ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

MODELLING THE RELATION BETWEEN ECOLOGICAL SUSTAINABILITY AND LAND-USE PLANS USING GIS TECHNIQUES

Ph.D. THESIS

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EKOLOJİK SÜRDÜRÜLEBİLİRLİK İLE MEKANSAL PLAN İLİŞKİSİNİN CBS TEKNİKLERİ KULLANILARAK MODELLENMESİ

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Date of Submission **: 10 July 2019**
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Aileme

FOREWORD

Understanding the dynamics of urban development has been one of my utmost aims in my professional career. Thereof I have been concentrating on two main aspects of urban areas. One of these aspects is to "understand the state of disaster risk" and the other is to be able to comprehend "sustainability characteristics". This research is an output of the latter one, and within this work, I tried to establish the link between land-use plans and ecological sustainability by developing a novel model and tool that enables to interpret how land-use plans affect ecological sustainability on the place it is implemented.

This has not been easy though, but the concept of "ecosystem services" and developed methodologies around this concept has been quite beneficial and helpful which enabled me to establish a new way of defining "ecological sustainability". In this research, these concepts are efficiently interlinked with urban development via land-use plans and hence, ecosystem services are used as a guiding mechanism for developing our cities for a more sustainable and resilient future.

In this regard, I would like thank to my advisor Prof. Azime TEZER, who guided me in all aspects of my research; introduced me to the "ecosystem services" concept and enhanced my awareness of how ecosystem services can be used as an efficient tool in urban development. Now I am looking forward to new challenges under her supervision and knowledge. I also would like to thank jury members Prof. Ergin TARI and Assoc. Prof. Doruk ÖZÜGÜL who provided invaluable feedback and led me to increase the concreteness and precision of the approach and methodology.

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I cannot find the exact words to righteously thank my mom, dad, and brother for devoting their lives to take care of my kids and making me feel comfortable at home and work, by all means.

Lastly, I would like to express my deepest feelings with my beloved wife who supported me in all levels of this research and fostered me to achieve better in all aspects of my life.

I hope and believe, my work will be a contribution to the path of reaching sustainable cities and a better future for the next generations.

July 2019   Emin Yahya MENTEŞE

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ABBREVIATIONS

CICES	**:**	Common International Classification of Ecosystem Services
EcS	**:**	Ecological Sustainability
EEA	**:**	European Environment Agency
EI	**:**	Environmental Impact
EMPI	**:**	Environmental Master Plan of Istanbul
EPA	**:**	Enivronmental Protection Agency (United States)
ES	**:**	Ecosystem Services
GIS	**:**	Geographic Information Systems
IMM	**:**	Istanbul Metropolitan Municipality
IPBES	**:**	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	**:**	International Union for Conservation of Nature
MAES	**:**	Mapping and Assessment of Ecosystems and their Services
MDG	**:**	Millenium Development Goals
OECD	**:**	Organization for Economic Cooperation and Development
SDG	**:**	Sustainable Development Goals
SEA	**:**	Strategic Environment Assessment
TEEB	**:**	The Economics of Ecosystems and Biodiversity
UN	**:**	United Nations
WB	**:**	World Bank

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MODELLING THE RELATION BETWEEN ECOLOGICAL SUSTAINABILITY AND LAND-USE PLANS BY USING GIS TECHNIQUES

SUMMARY

Sustainable development is one of the most addressed issues in the last decade and it aims at effective and apprehensive use of natural resources while ensuring social cohesion and economic prosperity. In this regard, urban development has a vital role in the sustainable development process since more than 50% of the world's population lives in cities and spatial planning of our living environment is the starting point for the establishment of cities. However, it is not easy to find a concrete and acknowledged approach for sustainability assessment in spatial planning because there is not enough proof to interpret the interaction between spatial plans and ecological sustainability. Therefore, the basic research aim of this thesis is to understand the link between spatial plans and ecological sustainability. In other words, it is aimed at creating a relationship model that enables us to understand how ecological sustainability changes when we make a change in space (land). In order to establish this relationship within a methodological framework, it is assumed that the ecological benefits provided by the spatial use types (such as forest, urban, recreational, etc.) must exceed the impacts caused by those types within the boundaries of a given space. Hence the difference between benefits and impacts must be in favor of benefits.

At this point, the concept of ecosystem services (ES) is used which provides an efficient approach to how nature serves and delivers benefits for human well-being. ES concept is known to be efficient in this aspect due to the correlation of ES with land-use/cover as observed in several studies. In literature, it is seen that ES mapping is an efficient tool for understanding the ecological capacity of an area that is widely used for directing and supporting planning decisions. In ES mapping, a simple approach is applied that enables to score the ES potential of spatial use types based on expert review and relevant data if possible.

Nevertheless, the ES mapping approach is not exactly suitable to evaluate the ecological sustainability of spatial plans since it is one-sided and takes into account only the benefits provided by the spatial use types. Thereof, to interpret the ecological sustainability performance of a plan; one must also consider the impact dimension because the spatial uses in a plan have negative outcomes as well as positive ones. In accordance, this study considers spatial plans as a source of ecosystem services and ecological impacts. In addition, areal quantity and integrity (patchiness) of a spatial use/cover type are regarded with the weights of relevant ecosystem services. This assessment is done with the aim of enabling a planner to compare the ecological sustainability level of a proposed plan with the current land cover's sustainability level. In order to improve the implementation, a simple GIS tool is developed that makes it available to make comparisons between two land-use/cover data. The performance of the developed tool is given in the related sections. Lastly, developed methodology is applied for Istanbul's environmental master plan of 2009 and Istanbul's land cover of the same period. By calculating both data's ecological sustainability performance,

possible change of sustainability level sourced from an environmental plan is interpreted.

As a result of this research, a novel method and GIS tool are developed that make it possible to use the ES concept as a proxy for ecological sustainability indicators for evaluating spatial plans. It is believed that developed methodology is useful for removing the lack of incorporation of ecological concerns within spatial planning and will foster the process of creating more sustainable cities in the future. It is also aimed at expanding the method to cover all types of ES to represent all tiers (ecological, social and economic) of sustainability notion by which a more comprehensive interpretation can be made by planners and decision-makers.

EKOLOJİK SÜRDÜRÜLEBİLİRLİK İLE MEKANSAL PLAN İLİŞKİSİNİN CBS TEKNİKLERİ KULLANILARAK MODELLENMESİ

ÖZET

BM'e göre günümüzde dünya nüfusunun yarısından fazlası kentlerde yaşamakta ve gelecek dönemde bu oranın %70'ler seviyesine çıkması beklenmektedir. Buna ek olarak, aynı süreç içinde dünya nüfusunun 9 milyar kişi seviyesine çıkacağı öngörülmektedir. Buna ek olarak kentsel gelişme dinamikleri ve eğilimlerinin, yerleşim alanlarının nüfus artış hızından daha hızlı arttığını göstermesinden hareketle; önümüzdeki 50 yıl içinde henüz yerleşime açılmamış alanların yerleşime konu olması kaçınılmazdır. Bu durumbaşta kent çeperlerindeki doğal veya yarı-doğal alanlar olmak üzere tüm habitat için çok büyük bir tehdit oluşturmaktadır.

Söz konusu gelişme ve yayılmanın, gerek kaynakların verimli kullanımı gerekse doğal çevre ile uyumlu olabilmesi amacıyla, sürdürülebilir kentleşme kavramı ve uygulamaları, günden güne ön plana çıkmakta ve mekansal planama alanında önem kazanmaktadır. Doğal kaynakların etkin ve doğru kullanımını sağlarken sosyal uyum ve ekonomik ilerlemenin sağlanmasını amaçlayan sürdürülebilir kalkınma kavramının şehircilik sektörüne adaptasyonu sonucu orataya çıkan sürdürülebilir kentleşme kavramı, özünde kentlerin daha sürdürülebilir bir şekilde oluşmasını hedefleyerek gelecek nesillere daha yaşanabilir yaşam alanları bırakmayı amaçlamaktadır.

Yapılaşmamış alanların yerleşime maruz kalmasına ek olarak mevcut yerleşimlerin yenilenme ve dönüşüm sürecinde de sürdürülebilirlik ilkelerinin belirlenmesi ayrıca büyük önem taşımaktadır. Halihazırda çok büyük nüfus kitlelerini barındıran bu alanlarda zaman içinde ihtiyaç duyulan yenilenme adımlarının,içinde bulunulan ekosistemin taşıma kapasitesini aşmaması yenilenen kentlerin çok daha uzun bir süre boyunca fonksiyonel kabiliyetlerini korumasını sağlayacak ekolojik açıdan sürdürülebilir olmasına büyük katkı sağlayacaktır.

Bu çerçevede mekansal planlamanın yerleşimlerin daha sürdürülebilir olmasına yönelik prensipleri adapte etmesi sürdürülebilir kalkınmanın temellerinden birini oluşturmaktadır. Mekansal planlamanın günümüzdeki uygulanma kriterleri ve yaklaşımları dikkate alındığında ise ekolojik önceliklerin yeterince kapsamlı ve detaylı bir şekilde sürece entegre edilmediği anlaşılmaktadır. Mevcut yerleşimlerin durumu ve kentlerin saçaklanma sürecinin önüne geçilememiş olması bunu destekleyen bir bulgu olarak literatürde tespit edilmektedir. Dolayısıyla mekansal planların ekolojik açıdan daha sürdürülebilir şekilde üretilmesi ve tasarlanması için öncelikli olarak plan-sürdürülebilirlik ilişkisinin kurulması gerekmektedir. Bu kapsamda, bu araştırma ile mekansal plan ve ekolojik sürdürülebilirlik ilişkisinin kurulması hedeflenmiş ve böylece daha sürdürülebilir kentler yaratılmasına yönelik temel bir katkı sunulması amaçlanmıştır.

Bu tez çalışması kapsamında sürdürülebilirlik kavramı yalnızca ekolojik boyutuyla ele alınmıştır. Bundaki temel gerekçe, sürdürülebilirlik kavramının temelinde yatan, ekolojik limitlerin aşılmaması gerekliliği, doğal kaynakların sınırlılığı ve gelişimin bu

kaynakların sağladığı imkanlarla kısıtlanmış olması kabulleridir. Ekolojik sürdürülebilirlik kavramına yönelik çalışmalar incelendiğinde, ekolojik sürdürülebilirliğin birçok farklı parametre ile tanımlanabildiği görülmektedir. Yürütülen çalışmanın niteliği, kapsamı ve mekanı gibi birçok bileşen, ekolojik sürdürülebilirliğe olan bakışı değiştirebilmektedir. Ancak her ne kadar çalışmalar arasında muhtelif farklılıklar bulunsa da, ekolojik sürdürülebilirliğe yönelik değerlendirmelerde hava kalitesi, su kalitesi, toprak kalitesi ve biyoçeşitlilik parametreleri kritik bir öneme sahiptir ve hemen tüm değerlendirmelerde ortak bileşenler olarak gözükmektedir. Fakat ekolojik sürdürülebilirlik endeksleri incelendiğinde, bu bileşenlerin mekan ile olan ilişkisinin kurulmadığı, yalnızca sahadan temin edilen verilerin uluslararası normalra olan uygunluğunun değerlendirildiği tespit edilmektedir. Bir başka ifade ile temin edilen verinin kaynağına inilmemektedir.

Buna ek olarak, mevcut literatür, mekansal planların da ekolojik sürdürülebilirlik kavramını yeterince adapte etmediğini beilrtmekle birlikte mekansal kullanım biçimlerinin yukarıda belirtilen hava, su, toprak kalitesi ve biyoçeşitlilik ile ilişkisi olduğunu bulgulamaktadır. Örneğin bir alan üzerinde sanayi tipi kullanım ile rekreasyon tipi kullanım arasındaki tercihten dolayı hava kalitesinde farklılık meydana gelebileceği rahatlıkla öngörülebilmektedir. Benzer şekilde orman kullanımı ile tarım kullanımı arasında, su kalitesi açısından belirgin bir farklılık bulunmaktadır. Diğer taraftan bu ilişkinin tam olarak nasıl şekillendiğini belirleyebilmek belli mekansal kullanım tiplerini temsil eden noktalarda çeşitli ölçümler (hava, su, toprak vb.) yapılmasını zorunlu kılmaktadır. Bu sayede belirlenen noktalardaki ölçüm değerleri ile mekanın o değerler üzerindeki etkisi belirlenebilmektedir. Bununla birlikte, söz konusu ölçümlerin yapılması gerek zaman, gerekse finansman açısından çok maliyetli olabilmekte ve böylece söz konusu ilişkinin kurulması için gerekli olabilecek optimum ölçüm kalitesine ulaşmak uygulanabilir olmamaktadır.Dolayısıyla mekansal kullanım türlerinin, ekolojik sürdürülebilirlik parametreleri ile olan ilişkisinin kurulmasında farklı ve uygulanabilir bir yöntem ve yaklaşıma ihtiyaç bulunmaktadır.

Bu noktada ekosistem servisleri kavramı çevreninin ve doğanın insan refahı için nasıl fayda ve hizmet sağladığını tanımlaması açısından etkin bir yaklaşım sunmaktadır. Planlanan çevrenin ekosistem potansiyelinin belirlenmesinde ve bu potansiyelin ne şekilde değişebileceğinin analiz edilmesine katkı sağlaması itibariyle; ekosistem servislerini dikkate alan yaklaşımlar gitgide yaygınlaşmaktadır. Ayrıca ekosistem servislerinin mekansal kullanım/arazi örtüsü ile doğrudan ilişkilendirebilecekleri için kullanışlı bir yöntem olduğu çeşitli çalışmalarda ortaya konmuştur. Söz konusu çalışmalarda ekosistem servislerinin planlama kararlarını yönlendirme ve destekleme konusunda önemli fayda sağladığı görülmüştür. Literatürde ekosistem servisleri haritalanması olarak ifade edilen bu yaklaşım ile, arazi örtüsünün sağladığı ekosistem servisi potansiyeli uzman görüşlerine bağlı olarak değerlendirilebilmekte ve böylece belli bir bölgedeki arazi örtüsünün nitelik ve niceliklerine bağlı olarak, ekosistem servisi potansiyeli hesaplanabilmektedir. Bu yaklaşım sıklıkla uzman görüşüne dayanmakla birlikte, araziden temin edilen ölçümler ile kalibre edilebilmekte ve böylece arazi kullanım-ekosistem servisi ilişkisi daha net kurulabilmektedir. Ekosistem servislerinin haritalanmasında kullanılan temel yaklaşım, mekansal kullanım tiplerinin 0-5 arası skorlanmasına dayanmaktadır.

Ancak ekosistem servisleri yaklaşımının mekansal kullanım çerçevesinde ve ekolojik sürdürülebilirliğin ölçülmesinde araçsallaştırılabilmesi için mekansal kullanımdan kaynaklanan olumsuz etkilerin de hesaplamaya entegre edilmesi gerekmektedir. Bu

doğrultuda bu çalışma ile mekansal planlarda önerilen kullanım türlerinin ekosistem servisleri sağladığı gibi, ekolojik etkiler de doğurduğu öngörülmüş ve ekosistem servislerinin haritalanmasında kullanılan 0-5 arası skorlama, -5 - +5 şeklinde genişletilmiştir. Bu sayede negatif değerlerin analizlere altlık olarak girmesi mümkün kılınmıştır. Hesaplamada, mekanın kullanımından kaynaklanan olumlu ve olumsuz yönlerin bir arada değerlendirilmesi sayesinde -ekolojik sürdürülebilirlik kavramının tanımlamalarında kullanılan ortak ifade ile-"ekosisteme yapılan etkinin ekosistemin taşıma kapasitesini aşmaması gerekliliği" takip edilebilmektedir.

Yöntemin temelini oluşturan bu yaklaşıma ek olarak mekansal kullanım türlerinin alansal büyüklüğü, fragmantasyon seviyesi ve sağlanan ekosistem servislerinin veya neden olunan ekolojik etki bileşenlerinin ağırlıklandırılması ile mekansal planların ekolojik sürdürülebilirlik seviyesi hesaplanabilmektedir. Böylelikle mekansal planların ekolojik sürdürülebilirli seviyesi hesaplanırken, ekosistem servisleri tabanlı ve bütüncül bir yaklaşım benimsenmiş olmaktadır. Aynı hesaplama adımlarının plana konu arazi örtüsünün ekolojik sürdürülebilirlik potansiyeli ile karşılaştırılması sonucunda önerilen planın mevcut durumu ekolojik açıdan daha ileriye mi yoksa geriye mi götürdüğü öngörülebilmektedir. Söz konusu karşılaştırmanın ve geliştirilen yöntemin global ölçekte genel geçerliği olması ve taksonomi standardizasyonu sağlanabilmesi açısından, mekansal kullanımın, Corine arazi örtüsü verisi ile eşleştirilerek işleme sokulması prensip olarak benimsenmiştir. Yani yöntemde girdi olarak kullanılan bir planda yer alan mekansal kullanım türlerinin hangi Corine arazi örtüsü türüne denk geldiği kullanıcı tarafından sisteme girilmektedir.

Bu noktadaki önemli hususlardan biri ekolojik sürdürülebilirlik kavramını tanımlarken kullanılacak olan ekosistem servisi göstergelerinin belirlenmesi olmuştur. Gerçekleştirilen literatür araştırmaları ve derlemeleri sonucunda, mevcut ekosistem servisleri çerçevelerinde yer alan ve genellikle "düzenleyici" olarak sınıflandırılan servisler dikkate alınmıştır. Söz konusu servisler ekolojik sürdürülebilirlik parametrelerinde yer alan hava kalitesi, su kalitesi, toprak kalitesi ve biyoçeşitlilik bileşenlerinin düzenlenmesiyle ilgili bileşenler içermektedir.

Geliştirilen yöntem sayesinde karar verici, uygulayıcıve/veya plancıların geliştirmiş oldukları plan önerilerinin mevcut arazi kullanımı ile karşılaştırması mümkün kılınmaktadır. Dahası, bu yaklaşımın etkin bir şekilde kullanımının sağlanması için CBS tabanlı bir yazılım ayrıca geliştirilmiştir. Geliştirilen yazılımda mekansal plan ve mevcut kullanım verisi .shp uzantılı olarak sisteme entegre edilmekte, bu esnada Corine arazi örtüsü taksonomisi ile eşleştirme yapılmaktadır. Kullanıcının girişi yapılan verilerin "alan" sütununu tanıtmasıyla tamamlanmakta ve sistem girişi yapılan her iki verinin ekolojik sürdürülebilirlik seviyesini hem grafik, hem de harita tabanlı olarak sunabilmektedir. Böylece geliştirilmiş planın mevcut arazi örtüsü ile olan karşılaştırması hem sayısal, hem de görsel olarak incelenebilmektedir. Geliştirilen bu özgün yazılımın, basit kullanım ve etkin gösterim teknikleri sayesdinde planlama süreçlerine yol göstermede önemli bir rol oynayacağı öngörülmektedir.

Son olarak geliştirilen yaklaşım ve yazılım, Istanbul 2009 Çevre Düzeni Planı ve o döneme ait güncel arazi kullanım verisi faydalanılarak test edilmiştir. Her iki verisetinin ekolojik sürdürülebilirlik değerinin hesaplanması ile çevre düzeni planının ekolojik sürdürülebilirliğe ne şekilde etki ettiği hesaplanmaya çalışılmıştır.

Sonuç itibariyle de bu araştırma sayesine mekansal planların değerlendirilmesine yönelik olarak, ekosistem servisleri kavramını ekolojik sürdürülebilirlik kavramına CBS tabanlı olarak entegre eden özgün bir yaklaşım geliştirilmiştir.

1. INTRODUCTION

The most used and agreed sustainability definition is the one made by the United Nations World Conference on Environmental Development (1987) in the Brundtland Report, stating that sustainability is a development approach that enables progress at present without risking the capacities of the future generations to improve themselves. There is a consensus that human activities must be sustainable and meanwhile, there has to be a fixed level of disruption of resources based on human activities that reduce the ability of this capital to sustain for humanity in the future (Arrow et.al, 1996). In the urbanization context, Alberti summarizes this approach by stating that urbanization must consider the limits of natural resources and act not only for the people living within the boundaries today but also the future generations as well (1996). In this regard, White and Whitney (1992) describe three parameters for a city to be sustainable: adaptation of best available technology (that leads to minimizing its impact on natural resources), having an ecological surplus (assuming that it exceeds its carrying capacity) and lastly, capability to compensate consumed economic values with ecological productivity capacity. Therefore, in order for a city to reach an optimum level of ecological sustainability, ecological concerns must be incorporated in the first step of urban development which is land-use planning. Nevertheless, there are limited numbers of approaches in this regard and most of these rely on conventional methodologies that mainly focus on the areal change of ecological assets proposed by spatial plans. On the other hand, the ecosystem services (ES) approach may offer significant opportunities for planners and decision-makers to incorporate ecological aspects within the decision making of the spatial planning process.

Within this general scope, the utmost aim of this research is to foster the urban development process by establishing a methodology to understand the relationship between ecological sustainability and land-use plans utilizing the ES approach.

1.1 Problem Definition and Hypothesis

There is a consensus on the definitions and concept of sustainability and most of the stakeholders have a similar perspective; the quantitative assessment (measurement) and/or monitoring of sustainability include a variety (Mayer, 2008). There is a concrete motivation in international bodies such as the United Nations (UN, 2015), the World Bank (WB, 2014), Organization for Economic Cooperation and Development (OECD, 2004) on trying to estimate the level of sustainability in the worldwide. In addition to these international bodies, there are also various research institutions dealing with the assessment of sustainability phenomenon, which bring a diverse and wide range of studies into literature.

In a review of these studies, it is seen that the most common way of sustainability assessment is to establish an index-based approach incorporating multiple indicators and variables. In this regard, each index has its own characteristics based on its location, thematic priority, purpose and context.

Although indexing is a very efficient tool for measuring the sustainability level, there are also criticisms on composite indices; claiming they are mostly championed by their creators (Parris and Kates, 2003). Moreover, Boehringer and Jochem (2007) indicate that most of the sustainability indexes ignore the scientific rules of the aggregation process that guarantees the consistency and meaningfulness of indexes. In addition, most of the indexes are developed for the purpose of ranking the spatial entities; based on relative evaluation (Mori and Christodoulou, 2012). However, sustainability is not a relativistic notion, because of the biophysical or ecological characteristics that are actually absolute (Fischer et. al., 2007). Esty et. al. (2005) supports this opinion by stating that a country can be unsustainable in terms of absolute evaluation even though it performs well in a relativistic index because assessing sustainability in such a way may be insignificant if all countries are on an unsustainable course. In a widely acknowledged approach by Cato (2009), it is indicated that all economic and social development process is limited to environmental limits. This statement fosters the aforementioned criticisms against composite indexes; which claim sustainability cannot be assessed via relative approaches since the environment itself is not limitless.

These criticisms on sustainability assessments constitute the basic argument of the research which is: the environmental dimension of sustainability should be the core

indicator (that others depend on) of sustainability concept and it is assumed that other aspects of sustainability such as social and economic issues are limited by environmental boundaries.

At this point, the difficult task is in assessing the goals that respond efficiently to the environmental aspects and how the progress can be monitored on the city scale (Shane and Graedel, 2000). Hence, the challenge is relating the ecological space with urban patterns (Alberti, 1996). Alberti informs that a useful set of indicators must give information about whether a city is performing well or not in means of certain sustainability criteria and how the performance and life quality of a city are related with "spatial structures". Thus, it is also important to understand the current state of spatial planning discipline by means of its sustainability performance. Because urban planning routine shapes the development of cities, organize transportation and infrastructure systems and aims at ensuring environmental and socio-economic well-being (Wheeler, 2013). On the other hand, according to Owens and Cowell (2002), spatial planning is one of the most important domains where assumptions of sustainable development are challenged. This is inevitable since the connection between urban plans and their implementation is mostly not solid as should be due to the lack of commitment and/or monitoring by local officials, political leaders and public stakeholders which may lead to control unsustainable development. Therefore, more efficient tools for urban planning must be developed for measuring and monitoring the impacts of the spatial plans on a sustainable future (Wheeler, 2013).

After a detailed literature review, covering the fields of landscape planning, landscape ecology, environmental impact assessment, ecosystem management; Leitao and Ahern (2002) remark that sustainable land-use planning is an inevitable outcome of the transformation of the planning discipline into the millennium in which harmony between present and future generations and the requirement to regulate development with ecological concerns are increasingly being incorporated into planning process and regulations (2002). As a result, environmental concerns are taking place in the urban planning agenda more and more where new methodologies are developed and new initiatives are established to assure environmental quality in the urbanization process (Dodman et.al., 2013). In this regard, a precise planning context enables to create sustainable communities in which an ecosystem perspective is a fundamental aspect to reach efficient spatial planning that contributes significantly to more sustainable

urbanization (TEEB, 2010). However, although spatial planning has a key role in sustainable urban development, "Global Report on Human Settlements" states that despite the acknowledgment of sustainability concept by many cities; none of them are fully able to address the needs of sustainable urban development (UN-HABITAT, 2009). As Vancouver Declaration (2006) indicates; it is of great importance to put the sustainability of habitats and ecosystems in the core of spatial planning in the path of reaching sustainable cities.

Thereof, incorporating ES into spatial planning might be a useful activity to ensure sustainability by bringing the importance of such services to light, and thereof providing a background to interpret exchange between ecological and socio-economic assets when developing new urban areas (Gret-Regamey et.al, 2017). ES approach also enables the decision-making process to be more transparent and more effective by means of resource use while improving sustainability by halting negative outputs of policy actions (Schaefer et. al., 2015). In the report of "A Green Vision for Sumatra", advantages and gains that can be obtained if an ES based spatial planning approach is adopted rather than conventional one and it is estimated that ES based planning approach results in net gains in quality of the habitat, total carbon stock and decreased nutrient pollution as well as in decreasing erosion in Sumatra region (Bhagabati et.al, 2012).

Within this context; the main research problem of this study can be summarized to define the relationship between ecological sustainability and spatial uses by establishing an ES based methodological framework. As a result; the hypothesis of this study is defined as *in order to remove deficiencies in consideration of environmental concerns in spatial planning; there is a certain need of tools to assess the ecologic sustainability performance of land-use plans in which ES can have a fundamental act, where ecological sustainability is equal to the difference between overall ES and ecological impacts (EI) caused by the land-use.*

1.2 Research Aim and Main Research Questions

Urban development induced ecological degradation is increasingly argued in the frame that land-use planning is not performing well by means of providing a healthy living environment. Although urban development is not solely dependent on the planning process and includes a variety of factors, plan making is the basis of the development.

Therefore, to achieve environmentally sustainable urban development; the planning process must result in the most viable way possible and produce sustainable plans in the first place. In this direction, the main aim of this research is to place sustainable development as a priority in the spatial planning procedure by indicating how strongly these two phenomena are connected.

In this regard, the first target of the research is to develop a sustainability assessment approach that enables planners and decision-makers to compare their plans' sustainability performance with current land-use or land cover; so that they can understand whether their plans are performing better or not by means of ensuring environmentally sustainable development in comparison with the level of existing situation.

Secondly, it is focused on developing a GIS tool that suits the needs of the methodology for providing the applicability of the approach and increasing the comprehensibility of the model. Because although there are many studies focusing on the assessment of the sustainability level, very few are integrated with GIS infrastructure. Therefore current sustainability assessment approaches require solid knowledge on the offered methodology and specific know-how to adopt these approaches in the urban development process.

In order to remove these gaps, it is aimed at developing a tool that can be systematically adopted for any spatial plan's environmental sustainability assessment and its comparison with a current land cover or an alternative plan. By this, a planner or decision-maker will easily be able to assess their spatial plan's sustainability performance that will lead them to enhance their judgments and to convince community perceptions.

To reach these objectives, the following research questions (RQ) are identified and investigated:

RQ1: Within spatial development context; how is ecological sustainability defined and measured within acknowledged frameworks and what are the main components of ecological sustainability?

RQ2: What is the current situation in considering the ecological concerns in the spatial planning process?

RQ3: How can ecosystems be utilized in order to understand the ecological sustainability level of land-use plans?

1.3 Research Strategy and Approach

The main axis of this research is addressing the impact of land-use plans' influence on ecological sustainability. As will be seen in the literature review sub-section, there is an extensive level of knowledge on the term of sustainability, land-use planning, and their relationship. This relation is mostly estimated via composite indices (Boehringer and Jochem, 2007; Mori and Christodoulou, 2012; Singh et.al, 2011).

Nevertheless, there are also criticisms on these indices; claiming they are mostly championed by their creators (Parris and Kates, 2003). Moreover, Boehringer and Jochem (2007) indicate that most of the sustainability indices ignore the scientific rules of the aggregation process that guarantees the consistency and comprehensiveness of the indices. In addition, most of those indices are made with the purpose of ranking the spatial entities; based on relative evaluation (Mori and Christodoulou, 2012). However, sustainability is not a relative notion, because of the biophysical and ecological boundaries that are actually absolute (Fischer et. al., 2007). Esty et. al. (2005) supports this opinion by stating that a country can be unsustainable in terms of absolute evaluation even though it performs well in a relativistic index because assessing sustainability in such a way may be insignificant if all countries are on an unsustainable course. In this regard, in a widely acknowledged approach by Cato (2009), it is indicated that all economic and social development process is limited to environmental limits (Figure 1.1). This statement supports the aforementioned criticisms against composite indices; which claim sustainability cannot be assessed via relative approaches since the environment itself is finite. Therefore, in this study, only the environmental aspect of sustainability is taken into consideration since it is the main indicator of sustainability concept which others depend on. It is presumed that economic welfare and social harmony are somehow limited to the environment, in other words, natural resources.

In order to overcome the shortcomings of relative indexing models, Bithas and Christofakis (2006) suggest analyzing critical levels of a biophysical structure where a disturbance occurs once these levels are exceeded.

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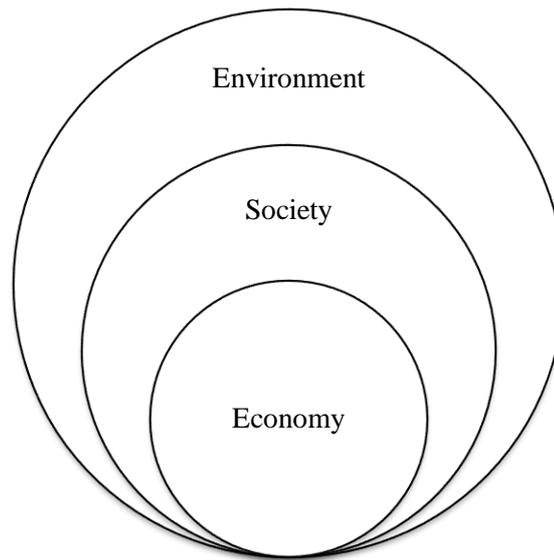
Figure 1.1 : Sustainability diagram. (Cato, 2009).

These levels are accounted for as limits of sustainability and reference points in this research. Finco and Nijkamp add that quantifiable metrics consisting of lowest levels and critical thresholds for sustainability assessment must be identified, analyzed and used to enhance approaches regarding sustainable development issues of today's cities (2001). These critics determine the main scope of the method of this research. The scope of the method is limited by analyzing the ecological dimension of "sustainability" and providing insight into the plans instead of planning procedures. The reason for working on the ecological aspect of sustainability is because it is assumed that the whole other versions of development are actually limited by environmental limits. In case these limits are exceeded, sustainability cannot be achieved. Therefore, first, one must consider the ecosystem thresholds within a planning area.

On the other hand; analytical assessment of ecological thresholds requires detailed data based on measurements, analyses, and surveys. For example, in order to analyze the air quality level of a given area and compare with thresholds, continuous monitoring of air components such as Carbon Monoxide (CO), Lead (Pb), Nitrogen Dioxide (NO_2), Ozone (O_3), Particulate matter (PM), Sulfur Dioxide (SO_2) is required (EPA, 2018). Moreover, monitoring such parameters must consist of a definite period to evaluate data accuracy and comprehend the exact structure of the air quality. In addition to air, the environment is composed of different types of categories such as soil structure, water quality/quantity, and biodiversity. Hence monitoring these

categories is also needed. Unfortunately, such measurements are mostly not in hand and even if they are accessed they mostly cover a limited area and do not include enough detail to assess ecological functions with relevant measurements. Therefore, in order to use such data, it is most likely to apply aggregation and neglect uncertainties. Thus, it makes it impossible to unify different sources and types of data and combine them into an index. In order to overcome this shortcoming and analyze the sustainability level of a specific area, the ES concept is utilized in this research. ES concept provides an efficient framework for evaluating the benefits provided by ecological characteristics in a particular area. Based on the methodology offered by Burkhard et.al. (2009, 2014), ES potential of specific land-use types can be assessed and mapped to measure and compare for both situations of the existing and planned. In this research in addition to ES potential, ecological impact (EI) capacity of land-use types is taken into account for a specific location and the difference between ES and EI potential is assumed as the ecological sustainability level for the particular area.

Another important aspect of the study is the consideration of land-use plans as an input of the analyses. Although there are several pieces of research and methodologies on "sustainable land-use planning" it is presumed that land-use plans are the final output of the planning process meaning that they are theoretically final decisions shaping urban development. Moreover, there is no similar approach that enables us to understand the possible impacts of spatial plans on ecological sustainability. Whereas, spatial plans are spatial instruments and can be incorporated into analytical measurements easily via GIS tools.

In this regard ES can play a substantial role in understanding the spatial component of sustainability provided by planning decisions. Recent studies on ES such as "Ecosystem Assessments in Europe and MAESS", "A synthesis of approaches to assess and value ES in the EU, in the context of TEEB (2013)", The Economics of Ecosystems and Biodiversity (TEEB), "The Common International Classification of Ecosystem Services (CICES)", "Intergovernmental Platform on Biodiversity & Ecosystem Services (IPBES)"; all highlight in detail the close relationship between land-use/cover and ES. Therefore, as being one of the basic instruments that shape land-use and development; spatial plans are one of the most critical tools that influence ES and hence ecological sustainability.

Within the background summarized above, this study focuses to develop an ecological sustainability assessment approach for urban plans, based on Burkhard et. al's ecosystem service mapping approach (2009) that provides an efficient tool for an understanding of the capacity of land-uses' ES provision. Nevertheless, since the aforementioned approach includes the service provision of land cover and ignores the impact side of it, the approach does not aim to provide an insight on the ecological surplus of space as mentioned by White and Withney (1992). In addition, land development threatens the capacity of ecosystems to provide these services (Colding, 2011; Niemelä et al., 2010). Hence, the impact of urban development should be an inseparable part of the definition of sustainability. In this regard, Burkhard et. al's (2009) approach has been modified by putting the impact dimension of land-use/cover into analysis to calculate the environmental sustainability level of land-use plans and land covers. The novelty of this approach is the assumption that ecological sustainability (EcS) level is equal to the difference between ES provision capacity and ecological impact (EI) caused. The difference is acquired by putting negative values into Burkhard et.al.'s (2009, 2014) matrix model and making a matrix summation with related factors of quantity, patch density and weight as explained in the method section.

Lastly, the ecological sustainability level is calculated for current land cover and the valid land-use plan for understanding the change in the EcS level. Because as the definition of sustainability suggests, the impact of land-use or urban development must not exceed the natural limits of the planned area by environmental means; in other words, ES potential provided by current land cover/land-use must not be surpassed by the proposed land-use types. From this point of view, the ecological sustainability of an area can be calculated as in Equation-1.

Ecological Sustainability = Ecosystem Services – Ecological Impacts   (***Equation-1***)

The conceptual diagram of the research is constructed as in Figure 1.2. The diagram also depicts how the optimum land-use planning process must be formed to ensure ecologically sustainable living environments.
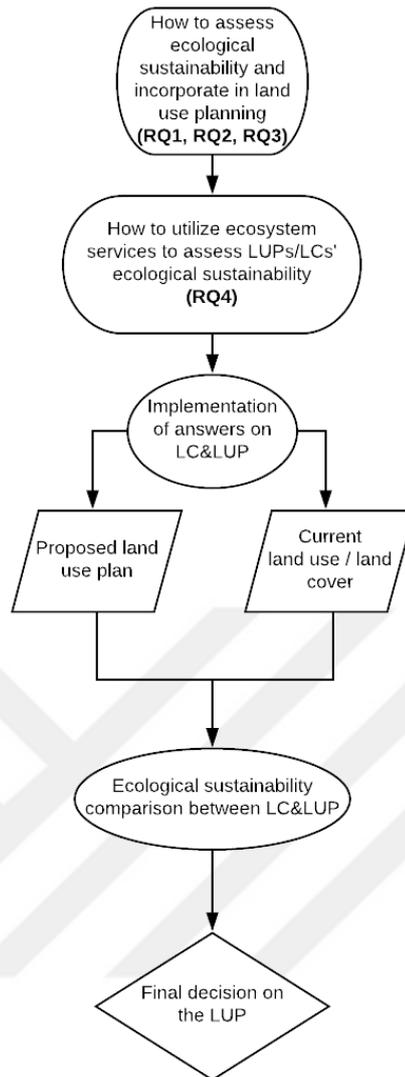
Figure 1.2 : Conceptual approach of the research methodology
(LC: Land Cover, LUP: Land-use Plan).

1.4 Thesis Structure

Based on the aforementioned background information about the research, the thesis is constructed to embrace all the process steps in detail. The first part of the thesis is "Introduction" and draws the outline of the research and explains the scope and approach in general. In the second chapter, answers are sought for the research questions based on an in-depth literature review. Afterward, in line with the literature review findings, the research approach is justified and detailed methodology is established in the "methodology" chapter. In the fourth chapter, implementation of the methodology is explained in a pilot case by comparing the ecological sustainability level of Istanbul's environmental master plan and land cover data for the year of 2006.

This part also serves as a validation analysis for the methodology and after it is proved that methodology is consistent; the development of the GIS tool takes part in the fifth chapter. This part includes the technical details of the GIS tool and a demonstration to assure the accuracy of the software. In the final part of the thesis "results&discussion" takes place and summarizes the study in general aspects, highlights the importance of the works done and explains the possible progress/enhancement options for the developed system. The flowchart of the thesis structure is given in Figure 1.3.
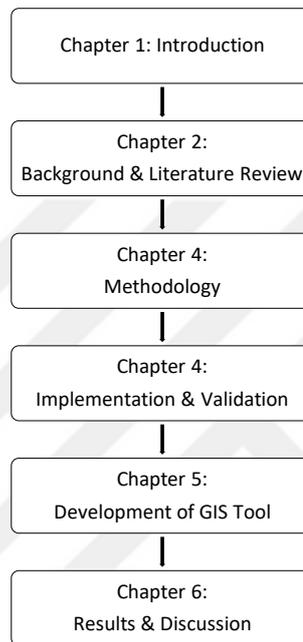
Figure 1.3 : Thesis outline.

2. BACKGROUND & LITERATURE REVIEW

Land-use planning is a process of organizing land-use options based on the ecological potentials and alternative patterns of the land and together with other physical, social and economic features of the space-based upon, in order to identify the most effective spatial organization and land-use type without compromising the natural resources or the ecosystems (UN-FAO, 2013). In this regard, a spatial plan is an analytical apprehension for the most expected state of space in the future or in other words: spatial plans define how space will be like in the future. Within this framework, "spatial planning" is considered as a term to describe the process to create a plan. Actually, spatial planning process includes a series of acts ranging from a solely technical aspect to managerial or governmental adjustments; moreover, it is also stated that spatial planning process aims at fostering the socio-economic structure of the communities, safeguarding the ecological sustainability, removing regional inequalities and enhancing the availability of resources through providing life quality and spatial justice (Christou et.al., 2006).

In this regard, spatial/land-use planning can be considered as one of the main tools that influence sustainability. Identification of this influence is the main aspect of this research but as indicated in several studies; it is hard to evaluate the environmental results of urban planning and it is complicated to relate urban space with ecological attributes (Shane and Graedel, 2000; Alberti, 1996). Moreover, it is even more difficult to assess the results of local action (plan) in a regional and/or global level. For example, limitation of food production in an area may conclude as an increase in land-use intensity elsewhere (Opdam et.al, 2018) which requires that researches must provide details on how local, regional, and global factors and impacts are connected (Verburg et al.2015). Nevertheless, it is also known that the requirement to improve the tools to analytically incorporate ecological approaches is still a gap within the discipline of spatial planning and there is a clear need for more efficient tools to measure and monitor the impacts of the spatial plans on sustainability (Wheeler, 2013).

Based on the literature review on the disciplines of landscape planning, landscape ecology, environmental impact assessment, and ecosystem management Leitao and Ahern remark that sustainable land-use planning is the unavoidable result of the transformation of the planning discipline where main notions of sustainability are increasingly being applied within planning procedures and regulations (2002). In addition, there are various researchers claiming that sustainability is one of the integral parts of the planning process (Forman, 1995; Grossman and Bellot, 1999). However, it has been observed that planning discipline wasn't rapid enough to fit into the principles of ecology (Leitao and Ahern, 2002). Therefore sustainability must be adopted more efficiently into the spatial planning process and administrating lands for which new tools are required (Leitao and Ahern, 2002) since its spatial component is tightly correlated to the inter-dependence of land-use types and to spatial changes such as fragmentation (van Lier, 1998).

In order to construct the relation between the spatial component of land-use and its ecological outputs; ES concept offers great opportunity since there is enough number of acknowledged proofs that identify the link between a land-use type and its ES capacity. Hereof, ES context can be used as a proxy to define the ecological sustainability level of spatial plans.

Within this scope, this section is constructed under four main categories. Firstly, in order to establish the link between spatial plans and ecological sustainability, at first one must understand the ecological sustainability and how it is measured. In line with this, the main components of ecological sustainability (air quality, water quality, soil quality, and biodiversity) must be addressed and their possible relation with land-use must be sought. Secondly, the scope and content of the sustainable land-use planning must be clearly defined in order to comprehend the level of incorporation of "sustainability" in actual planning procedures. Thirdly, ES must be evaluated in-depth to assess its potential to be used as an interface in measuring the ecological sustainability level of land-use plans. Lastly, in this section, an overall evaluation of the literature review is provided to produce answers for "research questions" and to validate the hypothesis.

2.1 Ecological Sustainability

In linguistic means, sustainability is basically the capability to be kept at a consistent rate or level (Oxford Dictionary). Based on the discipline or the sector that sustainability is taken into account; the term sustainability shows a significant level of variance. In accordance, parameters used to understand sustainability can change considerably. In the scope of this research, the sustainability concept is deemed within the context of development. In this regard, the definition of "sustainable development" is almost entirely acknowledged as stated in Brundtland Report (1997) by "*Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs*".

In order to integrate the "sustainability" approach into "spatial planning", understanding how sustainability is measured and interpreting the part of ecological sustainability within this context play a vital role. In this regard, literature shows that there are solid knowledge and efforts on measuring sustainability in different scales and ecological aspects are the most critical tiers of the phenomenon. Therefore, in this literature review; first; it is aimed to understand how ecological sustainability is measured in different contexts and second; the components of ecological sustainability are sought.

2.1.1 Measuring sustainability

In contrast with its widely acknowledged definition, there is a variety of approaches, methods or models in assessing sustainability. One of the most common ways of assessing sustainability is creating indexes based on sub-parameters and making comparisons between entities such as countries, cities, towns, etc.

Since the Rio Declaration announced in 1992, evaluating sustainable development has become one of the main research fields (Özügül and Cengiz, 2011). According to the reviewed literature, there are various sustainability indicators identified in several studies depending on their location, priority and special circumstances. There are also useful literature reviews on sustainability assessment topics such as Boehringer & Jochem (2006) and Singh et.al (2011)'s studies.

"Millennium Development Goals" are of the most comprehensive and acknowledged document initiated by the United Nations in 2000 providing an umbrella for all similar

types of studies and relevant actions. The Millennium Development Goals (MDGs) comprise of eight international level development targets that were adopted after the Millennium Summit of the United Nations in 2000, following the adoption of the United Nations Millennium Declaration to reach the below mentioned Millennium Development Goals by 2015:

- To eliminate extreme poverty and hunger
- To reach universal primary education
- To advocate gender equality and empower women
- To decrease child mortality
- To enhance maternal health
- To fight against HIV/AIDS, malaria, and other diseases
- To assure environmental sustainability
- To establish an international partnership for development

The seventh article of these targets is to guarantee environmental sustainability. As a result, environmental sustainability becomes one of the main concerns of the countries and in order to attain environmental sustainability, several indicators (mentioned as targets) are specified as listed below:

Target 7A: Incorporate the standards of sustainable development into country regulations and programs and prevent the loss of ecological assets.

Target 7B: Decrease biodiversity loss by 2010, measured via a decrease rate of losses in the following indicators:

- The ratio of land area covered by forest
- CO_2 emissions,
- Use of substances harmful for the ozone
- The ratio of fish stocks
- The ratio of water resources use
- The ratio of conserved terrestrial and aquatic areas
- The ratio of species under risk of extinction

Target 7C: Halve, by 2015, the ratio of the population that has no sustainable access to safe drinking water and fundamental sanitation. This target is followed by the indicators below:

- The ratio of the population with sustainable access to an enhanced water source,

- The ratio of urban population with access to improved sanitation

Target 7D: By 2020, reaching up to a compelling development in the lives of at least100 million slum-dwellers

- The ratio of the population living in urban slums

Based on the outputs of the Millennium Declaration; Report on World Summit on Sustainable Development - WSSD (2002) emphasizes the importance of setting up relevant indicators to track the progress of sustainable development of the countries, regions, and cities. The studies referred to hereafter can all be seen as an action to reach the MDG's with the motivational and political background of WSSD.

The Ecological Footprint (EF) (Wackernagel and Rees, 1997) in most general terms; measures how rapidly human exhausts resources and produce waste compared to how rapidly nature compensates waste and generates new resources. Each city, state or nation's Ecological Footprint can be evaluated and interpreted based on its bio-capacity. Herein, if a population's Ecological Footprint surpasses the area's bio-capacity, that means, the area has an ecological deficit. EF makes a comparison for any given population by quantifying how much the mutually exclusive, biotic productive area must be used to ensure its resource supplies and to assimilate its wastes". Wackernagel and Rees (1997) also state that EF is used to carry out assessments at the national and global levels.

The Ecoindex Methodology achieved significant recognition that evaluates the impact of various products, services, lifestyles (Chambers and Lewis, 2001). Chambers et al., (2000) mainly developed the Eco-Index Methodology for implementing EF analysis. The analysis comprises "component (top-down)" or "bottom-up" approaches which are coherent with the "component" approach that acquires data from international commerce statistics. In order to calculate EF conversion factors, whole life cycle data is used for most of the critical parameters (component). EF is normalized by the application of equivalence factors.

Living Planet Index (LPI) is one of the most acknowledged indices used as a global biodiversity assessment tool developed by WWF (1998). LPI depends on the estimation of trends of more than 2000 populations of over 1100 species of vertebrates

in terrestrial and aquatic ecosystems. The base year of LPI is accepted as 1970 and the index value for 1970 is considered as the scale for other years' evaluations. Boehringer and Jochem (2007) state that LPI is the ratio between living populations for each species between the current and previous year. The geometric mean of the proportions of different species multiplied with the index value of the former year provides the biodiversity index for the respective indicator.

In the SENSOR (Sustainable Impact Assessment: Tools for Environmental, Social and Economic Effects of Multifunctional Land-use in European Regions) project, indicators provide a proxy to assess the sustainability of land-use changes and related (policy) options with respect to their impacts on a range of ecological, economic and social issues (Helming et.al, 2008). In the project, nine main indicators are identified to represent the ecological aspect of sustainability (Table 2.1). Within this project, economic and social aspects are also incorporated as different indices that brings together a wide range of indicators that enables a holistic approach to evaluate sustainability impact assessment. SENSOR Project's approach is notable by means of analyzing sustainability impact based on the "land-use change" process, which is significantly related to the aim and scope of this thesis study.

Table 2.1 : Environmental indicators within the SENSOR project.

air quality
water quality and resources
soil quality and resources
climate
renewable or non-renewable resources
biodiversity, flora, fauna, and landscapes
land-use
waste production / generation / recycling
the likelihood or scale of environmental risks

In another study, sustainable development indicators are developed by Department for Food, Environment and Rural Affairs (UK) in 2013 to generate an outlook of national scale achievement level in the path of reaching a more sustainable economy, society, and environment. The SDIs are considered as tools for interpreting whether the country is developing sustainably as a whole, and they are also used as a mechanism for

decision-makers to have more sustainable policy actions. Since SDIs are used at the national level, they are not exactly suitable to be used for specific purposes such as local level land-use change. The assessment includes traffic light methodology and represents the overall change in the scores from the reference year to the latest year. In the assessment, four main indicators as "greenhouse gas emissions", "natural resource use", "wildlife: bird population indices" and "water use" that are defined with nine sub-indicators as shown in Table-2.1.

Table 2.2 : Sustainable Development Indicators developed for the UK by Department for Food, Environment and Rural Affairs (2013).

The main indicator set	Sub-indicator set
Greenhouse gas emissions	– UK greenhouse gases emissions – Greenhouse gas emissions associated with UK consumption
Natural resource use	– Raw material consumption of non-construction materials – Raw material consumption of construction materials
Wildlife: bird population indices	– Farmland birds, – Woodland birds – Seabirds – Water and wetland birds
Water use	– Abstractions from non-tidal surface waters and groundwaters

In another research developed by Fiksel et. al. (2012) for US Environmental Protection Agency (EPA), the adoption of sustainability indicators in EPA's decision-making process was aimed to supply efficient methods and guidance particularly within the Office of Research and Development's (ORD) research programs, It is also stated that more than 50 resources are reviewed after the initial review of well-known resources such as United Nations, World Bank, and OECD.

Within this study, sustainability indicators are categorized both in their use in spatial scale and functional base. It is indicated that ORD has developed an innovative "triple value" (3V) framework that enables to evaluate the interactions between economic, societal, and ecological systems. In a sample scheme presented in Figure 2.1, the relation between industry, society and environment is given that depicts the values created by each tier.
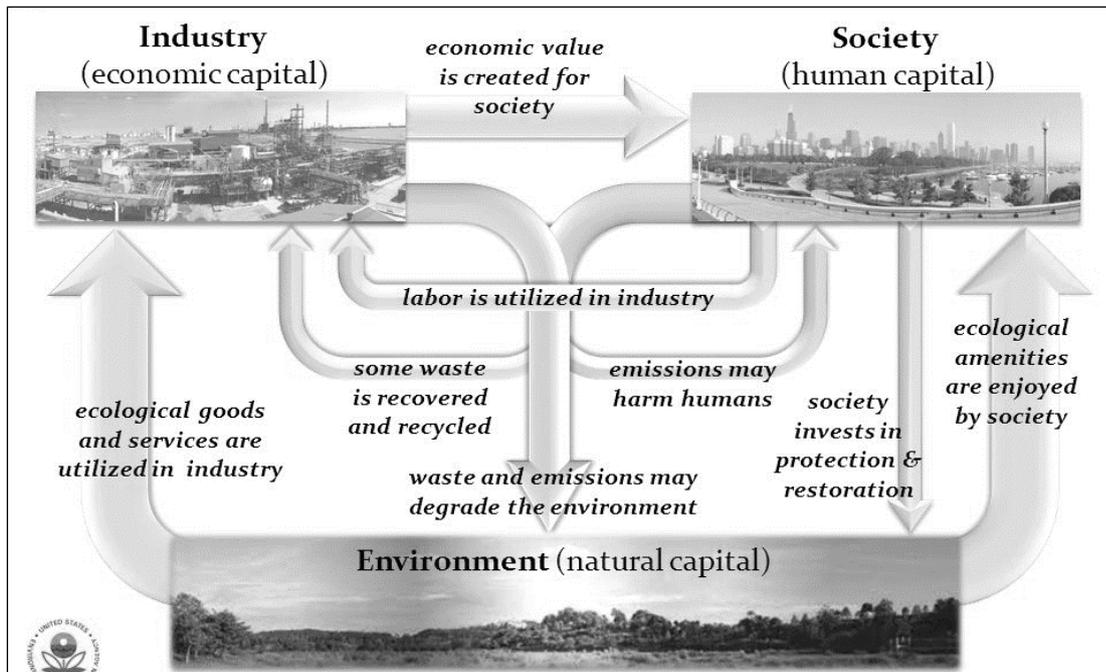
Figure 2.1 : Triple Value Framework Model (Fiksel et.al., 2012).

There are four main components of indicators that are applicable to these systems:

- Adverse Outcome (AOI) –evaluates the loss of value based on impacts upon individuals, communities, business enterprises, or the natural environment.

- Resource Flow (RFI) - evaluates pressures correlated with the ratio of depletion of resources, including materials, energy, water, land, or biota.

- System Condition (SCI) –evaluates the state of the systems in question, i.e., individuals, communities, business enterprises, or the natural environment.

- Value Creation (VCI) – evaluates the creation of value (both economic and well being) through enhancement of individuals, communities, business enterprises, or the natural environment.

Indicator sets provided in this study is given in Figure 2.2 in detailed.

In another study named "PLUREL" (an acronym for "Peri-urban land-use relationships Strategies and sustainability assessment tools for urban-rural linkages"), it is aimed at developing new mechanisms for sustainable rural and urban land-use relationships. In this regard, specified objectives are addressed to:

Indicator Category	Indicator Types	National Scale Examples	Community Scale Examples
Resource Flow Indicators	• Volume • Intensity • Recovery • Impact • Quality	• Greenhouse gas emissions • Material flow volume • Resource depletion rate	• Greenhouse gas emissions • Material flow volume • Water treatment efficacy • Recycling rate • Land use
Value Creation Indicators	• Profitability • Economic Output • Income • Capital Investment • Human Development	• Cost (reduction) • Fuel efficiency (gain) • Energy efficiency (gain)	• Cost (reduction) • Fuel efficiency (gain) • Energy efficiency (gain) • Vehicle use (miles per capita)
Adverse Outcome Indicators	• Exposure • Risk • Incidence • Impact • Loss • Impairment	• Health impacts of air pollution • Public safety • Life cycle footprint of energy use	• Health impacts of air pollution • Public safety • Sewer overflow frequency
System Condition Indicators	• Health • Wealth • Satisfaction • Growth • Dignity • Capacity • Quality of Life	• Air quality • Water quality • Employment • Household income	• Air & water quality • Local employment • Local household income • Housing Density • Infrastructure durability • Community educational equity

Figure 2.2 : Indicator system offered by ORD (Fiksel et.al., 2012).

- Develop frameworks and strategies to improve the perception and management of interactions among rural, peri-urban and urban land-uses

- Analyze and evaluate the appeals and competition for resources in Rural-Urban regions

- Develop land-use scenarios for Rural-Urban regions in Europe

- Establish a Generic Sustainability Impact Assessment Tool for Rural-Urban relations

- Implement approaches for the evaluation of the costs of decisions related to the urbanization process

- Improve cooperation among decision-makers, stakeholders, planners, and researchers through the establishment of new mechanisms

As a result of the PLUREL project, the development of the Integrated Impact Analysis Tool (iIAT)is one of the most important outputs, which can be used as a decision support mechanism. iIAT is a web-based tool displaying results in the form of spidergrams. These spidergrams act as a platform that lets an efficient and holistic perception of multilevel information that allows visualization of the changes in

sustainability indicators, as positive or negative trends based on different schemes are immediately visible as variations in the lines of the spidergrams (Figure 2.3).
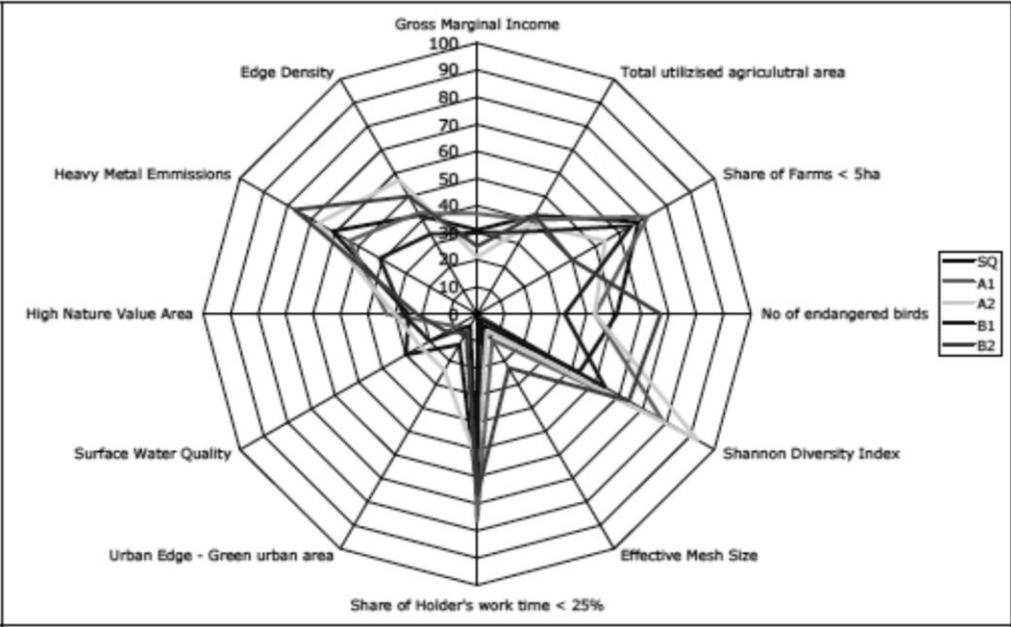
Figure 2.3 : Spidergram displaying the integrated analysis of urbanization impacts on sustainability in PLUREL project.

Within iIAT, 2000 is selected as a reference year and four different scenarios were produced for future development. The main aim of the developed tool was to establish awareness on how sustainability could vary in different locations and express the requirement on how policy interventions should also differ based on thematic and spatial characteristics.

The concept of the PLUREL study includes three different levels. In Level-1 three main pillars of sustainability namely economic, social and environmental in the EU27-scale. Level 2 enables a more detailed understanding of future scenarios based on seven categories as food production, living environment, economic performance, income, demography, regulation, and housing.

In environmental tier (environmental impact) at level 3, the indicators are identified as habitat and biodiversity, recreational value and ecological regulation function (Figure-2.4). All indicators are computed in the form of land-use (change) response functions and represent mathematically bivariate regression functions.

Indicators of the iIAT-EU
Environmental
Density of Natural Habitats
Endangered Bird Species
Landscape Interspersion
Landscape Patchiness
Landscape Fragmentation
Soil sealing
CO Emissions
HC Emissions
NOx Emissions
Heavy Metal Emissions

Figure 2.4 : Environmental indicators of the PLUREL project.

European Green City Index (EGCI) is a composite indicator set, aiming to assess and evaluate the ecological quality of 30 European cities based on specific aspects. By that, EGCI provides a tool that aims to improve the insight and policy-making capabilities of all stakeholders related to environmental impact assessment, from individuals to leading urban decision-makers. The index includes 30 different indicators per city that corresponds to a range of environmental aspects – from water depletion to waste treatment, air quality and transportation- and lists cities using a clear, concise and reproducible scoring procedure. The given performance scores of cities for specific indicators and overall scores as well enable to directly compare cities with each other. Based on the assessment, cities are rated in a spidergram similar to the PLUREL study (Figure 2.3). The components of the European Green City Index is given in (Figure 2.5).

Figure 2.5 : Main indicator sets used in European Green City Index.

List of categories, indicators and their weightings

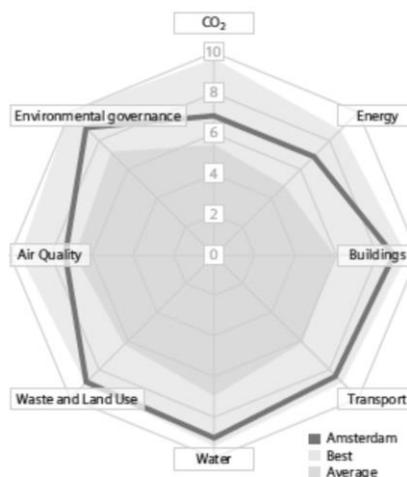| Category	Indicator	Type	Weighting	Description	Normalisation technique
CO_2	CO_2 emissions	Quantitative	33%	Total CO_2 emissions, in tonnes per head.	Min-max.
	CO_2 intensity	Quantitative	33%	Total CO_2 emissions, in grams per unit of real GDP (2000 base year).	Min-max; lower benchmark of 1,000 grams inserted to prevent outliers.
	CO_2 reduction strategy	Qualitative	33%	An assessment of the ambitiousness of CO_2 emissions reduction strategy.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Energy	Energy consumption	Quantitative	25%	Total final energy consumption, in gigajoules per head.	Min-max.
	Energy intensity	Quantitative	25%	Total final energy consumption, in megajoules per unit of real GDP (in euros, base year 2000).	Min-max; lower benchmark of 8MJ/€GDP inserted to prevent outliers.
	Renewable energy consumption	Quantitative	25%	The percentage of total energy derived from renewable sources, as a share of the city's total energy consumption, in terajoules.	Scored against an upper benchmark of 20% (EU target).
	Clean and efficient energy policies	Qualitative	25%	An assessment of the extensiveness of policies promoting the use of clean and efficient energy.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Buildings	Energy consumption of residential buildings	Quantitative	33%	Total final energy consumption in the residential sector, per square metre of residential floor space.	Min-max.
	Energy-efficient buildings standards	Qualitative	33%	An assessment the extensiveness of cities' energy efficiency standards for buildings.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
	Energy-efficient buildings initiatives	Qualitative	33%	An assessment of the extensiveness of efforts to promote energy efficiency of buildings.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Trans-port	Use of non-car transport	Quantitative	29%	The total percentage of the working population travelling to work on public transport, by bicycle and by foot.	Converted to a scale of 0 to 10.
	Size of non-car transport network	Quantitative	14%	Length of cycling lanes and the public transport network, in km per square metre of city area.	Min-max. Upper benchmarks of 4 km/km² and 5 km/km² inserted to prevent outliers.
	Green transport promotion	Qualitative	29%	An assessment of the extensiveness of efforts to increase the use of cleaner transport.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
	Congestion reduction policies	Qualitative	29%	An assessment of efforts to reduce vehicle traffic within the city.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Water	Water consumption	Quantitative	25%	Total annual water consumption, in cubic metres per head.	Min-max.
	Water system leakages	Quantitative	25%	Percentage of water lost in the water distribution system.	Scored against an upper target of 5%.
	Wastewater treatment	Quantitative	25%	Percentage of dwellings connected to the sewage system.	Scored against an upper benchmark of 100% and a lower benchmark of 80%.
	Water efficiency and treatment policies	Qualitative	25%	An assessment of the comprehensiveness of measures to improve the efficiency of water usage and the treatment of wastewater.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Waste and land use	Municipal waste production	Quantitative	25%	Total annual municipal waste collected, in kg per head.	Scored against an upper benchmark of 300 kg (EU target). A lower benchmark of 1,000 kg inserted to prevent outliers.
	Waste recycling	Quantitative	25%	Percentage of municipal waste recycled.	Scored against an upper benchmark of 50% (EU target).
	Waste reduction and policies	Qualitative	25%	An assessment of the extensiveness of measures to reduce the overall production of waste, and to recycle and reuse waste.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
	Green land use policies	Qualitative	25%	An assessment of the comprehensiveness of policies to contain the urban sprawl and promote the availability of green spaces.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Air quality	Nitrogen dioxide	Quantitative	20%	Annual daily mean of NO_2 emissions.	Scored against a lower benchmark of 40 ug/m³ (EU target).
	Ozone	Quantitative	20%	Annual daily mean of O_3 emissions.	Scored against a lower benchmark of 120 ug/m³ (EU target).
	Particulate matter	Quantitative	20%	Annual daily mean of PM^{10} emissions.	Scored against a lower benchmark of 50 ug/m³ (EU target).
	Sulphur dioxide	Quantitative	20%	Annual daily mean of SO_2 emissions.	Scored against a lower benchmark of 40 ug/m³ (EU target).
	Clean air policies	Qualitative	20%	An assessment of the extensiveness of policies to improve air quality.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
Environ-mental gover-nance	Green action plan	Qualitative	33%	An assessment of the ambitiousness and comprehensiveness of strategies to improve and monitor environmental performance.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
	Green management	Qualitative	33%	An assessment of the management of environmental issues and commitment to achieving international environmental standards.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.
	Public participation in green policy	Qualitative	33%	An assessment of the extent to which citizens may participate in environmental decision-making.	Scored by Economist Intelligence Unit analysts on a scale of 0 to 10.

Figure 2.6 : European Green City Index components.

In "SOLUTIONS" project, carried out by Echenique et.al (2010) it is aimed to understand the limits of planning practices in cities and towns that guide policymakers to make urban development ecologically sustainable, economically effective and socially inclusive. In order to achieve these goals, researchers first selected the policy instruments; secondly, simulated attitudinal responses to developed actions benefiting from the best city/region models; and third, they used these projections to evaluate the 26 sustainability metrics (Table 2.3).

Table 2.3 : Sustainability parameters used in SOLUTIONS project.

DOMAIN	THEME	INDICATOR
Economic	Net Economic Benefit (NEB)	NEB as money (£1997) needed to leave population unaffected by the policy (Hicksian compensation). Includes costs to exogenous employment and costs to inactive households.
	Feasibility	Transport Cost-Benefit Analysis in which transport user and transport operator benefits are calculated.
Natural Resources	Land	Area of land (km2) required to support residential, commercial/industrial development and required highway capacity.
	Energy	Energy use (Pj/yr) inland transport, residential dwellings (heating and lighting) and commercial and industrial buildings.
	Materials	New residential and commercial/industrial floor space (million m2), asa proxy for construction materials requirement.
Environment	Atmosphere	Greenhouse gas emission (Mt/yr CO2) from road transport, dwellings (heating, lighting) and commercial buildings. Emission of noxious gases (CO, NOx, VOC) and fine particulates (PM10)(Kt/yr)
	Water/flood	Surface sealing as the mean and 90th percentile of zonal percent surface impermeability
	Biodiversity	Area (% total) with receiving waters likely to experience (a) some or (b)severe loss of aquatic biodiversity due to urban development Change in terrestrial biodiversity (native species richness as % of non-agricultural/rural areas)
Social	Health	Road traffic accidents as personal injury accidents by severity, and accident costs (£/yr) Noise: Extent of road network above 65db(A) LA10,18h; Population (% of total) in zones with average road traffic noise above specified levels Route stress: % road network with high driver stress Residential crowding: Population (%) resident in homes below a space per capita threshold which returns 10% of the population in the base year.
	Opportunities	Vitality: A unit-less index value that reflects changes in the number of inhabitants and retail and leisure services in an area. Severance: % road network with pedestrian crossing times above specified thresholds in seconds.
	Equity	Social segregation: concentration of low income (SEG4 and inactive)households (Gini index) Equity in living costs: Change in household costs for low and high-income socioeconomic groups (% increase from 1997) Environmental equity: social distribution of road traffic noise and emissions to air (NOX, PM10). (Gini index of concentration of environmental quality and low-income households)

The research is notable with the skeptic approach to compaction, stating the lack of concrete supporting proof as to the environmental, economic and social impacts of the notion of compact cities. The study assumes the 1997 and 2001 years as base years for the assessment of the selected cities (Wider South East Region, Tyne & Wear City Region, Cambridge Sub-region). Thereafter comparison between 4 different scenarios (current trends, compaction, dispersal, expansion) until 2031 is made according to the sustainability metrics. In the study, the indicators show the difference from each other

by means of their units and while sometimes they are absolute values, sometimes they are percentage values. The positive point about the approach is that it does not use a composite index, but instead, benefiting from a base year for evaluation comparison is made respectively for each indicator for four different scenarios.

Above and among all of these invaluable researches, starting with Millennium Development Goals, the UN has always been setting the frame of sustainability research and currently the most respected and acknowledged work is Sustainable Development Goals that were produced by UN in 2015. Agenda 2030 and the Sustainable Development Goals that were accepted by all member states of the United Nations in 2015, identify a global framework that is valid to and must be utilized by all member countries (UN, 2015). The SDGs rely on the progress of the Millennium Development Goals (MDGs) and targets to bring an end to all forms of poverty (ibid). SDGs are uniquely designed as a call for action for all member countries whether poor, rich or middle-income; to advocate well-being while protecting the earth. It is indicated that while dealing with climate change and ecological conservation; ending poverty is a process that must proceed in coordination with strategies of economic growth and it must include a range of social requirements including health, education, social protection and job opportunities (UN, 2015). Solid measures and data are vital for converting the SDGs into practice for problem-solving by (i) activating governments, academia, civil society, and business; (ii) developing a report card to follow progress and assure transparency; and (iii) acting as an administration tool for the evolution required to reach the SDGs by 2030 (Sachs et.al., 2017). SDGs compose of 17 independent but complementary themes (Table 2.4).

Table 2.4 : Sustainable Development Goals (UN, 2015).

Sustainable Development Goals (SDGs)	
Goal 1.	*End poverty in all its forms everywhere*
Goal 2.	*End hunger, achieve food security and improved nutrition and promote sustainable agriculture*
Goal 3.	*Ensure healthy lives and promote well-being for all at all ages*
Goal 4.	*Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*
Goal 5.	*Achieve gender equality and empower all women and girls*
Goal 6.	*Ensure availability and sustainable management of water and sanitation for all*
Goal 7.	*Ensure access to affordable, reliable, sustainable and modern energy for all*
Goal 8.	*Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all*
Goal 9.	*Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation*
Goal 10.	*Reduce inequality within and among countries*
Goal 11.	*Make cities and human settlements inclusive, safe, resilient and sustainable*
Goal 12.	*Ensure sustainable consumption and production patterns*
Goal 13.	*Take urgent action to combat climate change and its impacts*
Goal 14.	*Conserve and sustainably use the oceans, seas and marine resources for sustainable development*
Goal 15.	*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*
Goal 16.	*Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels*
Goal 17.	*Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development*

2.1.2 Main components of ecological sustainability

Based on the literature review above, it can be clearly stated that the environmental aspects of sustainability are the backbone of sustainability indexes. Meanwhile, all of these indexes are unique by means of their approach, scope, aim, and location. Hence, it is difficult to assume one of these models as universal consent and imply it to a

specific study such as this research. Therefore in order to develop the appropriate sustainability indicators, almost all of these acknowledged sustainability indices can be reviewed in a matrix as given in Table 2.5 that is created to understand their extent.

As seen in this table and the previous section where indices are reviewed, there is a different type of indicator defined to assess the sustainability phenomenon but it is also obvious that there is a common pattern in their way of analysis. In reviewed indices, main indicator sets are "Air Quality", "Water Resources & Quality", "Soil Quality", "Biodiversity", "Energy", "Climate", and "Waste". Uncategorized indicator sets are depicted under the "other" column.

Among these indicator groups; the most common indicator sets are grouped under "air", "water", "soil" quality/quantity and "biodiversity" themes. Naturally, there are some overlaps or conflicts on how an indicator is considered within the indices (for example CO_2 level can be used under climate theme or energy theme in different studies) based on the scope of the sustainability frameworks. Still, the commonness of the main indicators is significant. Thereof, more focused emphasis on these four fundamental themes is put and a detailed review is carried out in forthcoming sections.

A review of these indicator frameworks shows that sustainability assessments mainly rely on best available data in hand that enables to evaluate the current situation. Thereof they mostly do not represent a future perspective that lets decision-makers take appropriate actions. Moreover, there is a certain lack of correlation between sustainability indicators and spatial/land-use features although it is known that spatial/land-use has a significant impact on them; especially by means of ecological aspects.

As a result, the review on sustainability metrics shows the commonness of the main indicator groups which is a critical finding for this research to shape the frame of the methodology. Meanwhile, it is also notable that sustainability assessment approaches mostly act as ex-post tools instead of ex-ante and they do not set the relationship between spatial/land-use properly.

Table 2.5 : Sustainability indices, parameters, and indicators identified through different policy documents and projects.

Project name	Institution	Air Quality	Water Resources & Quality	Soil Quality	Biodiversity	Energy	Climate	Waste	Other
Millennium Development Goals (2000)	United Nations	- CO_2 emissions, total, per capita and per $1 GDP (PPP) - Consumption of ozone-depleting substances protected.	The proportion of terrestrial and marine areas protected	The proportion of terrestrial and marine areas protected	- The proportion of land area covered by forest - The proportion of fish stocks within safe biological limits - The proportion of total water resources used - The proportion of terrestrial and marine areas protected - The proportion of species threatened with extinction	-	-	-	-The proportion of the population with sustainable access to an improved water source, urban and rural - The proportion of the urban population with access to improved sanitation
Sustainable Development Indicators (2013)	Department for Food, Environment and Rural Affairs	Greenhouse gas emissions	Water use		Wildlife: bird population indices				Natural resource use

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Table 2.5 (continued) : Sustainability indices, parameters and indicators identified through different policy documents and projects.

Project name	Institution	Air Quality	Water Resources & Quality	Soil Quality	Biodiversity	Energy	Climate	Waste	Other
Sustainable City Index (2014)	Sustainable Society Foundation	- CO2 emissions per capita per year	- The water consumption per year as a percentage of total available renewable water resources.	-	- the 10-years change of forest area - the size of protected areas in % of the total land area of a country	- energy use in tons of oil equivalents (toe) per person - energy savings 2008-2012 in % (source: IEA) -consumption of renewable energy as % of total energy consumption	-	- The Ecological Footprint has been used minus the Carbon Footprint	-
SENSOR (Sustainable Impact Assessment Tool) (2010)	FP6 Project Consortium	-Ammonia emission from agriculture -Nitrogen oxide (NOx) emissions	- Nitrogen (N) and phosphorus (P) surplus - Water abstraction - Water retention capacity of the soil	- Soil erosion risk by water - Soil sealing - Wind erosion - Soil carbon content	- Terrestrial habitats at risk from eutrophication - Farmland & woodland birds - Deadwood - High-nature-value farmland - Spatial cohesion - Pesticide use	- Renewable energy production and biomass - Energy used by transport - Energy used for heating and electricity	- CO2 emission - Methane and nitrous oxide emission - Carbon sequestration in biomass, soil and dead organic matter	-Discharge of sewage water due to tourism - Generation of municipal waste by tourists	-Land-use Change - Forest fire risk - Flood risk

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Table 2.5 (continued) : Sustainability indices, parameters, and indicators identified through different policy documents and projects.

Project name	Institution	Air Quality	Water Resources & Quality	Soil Quality	Biodiversity	Energy	Climate	Waste	Other
Sustainable Cities Index Ranking in Australia (2010)	Australian Conservation Foundation (ACF)	Level of particulate matter	Average residential water supplied per property		- Habitat Connectivity - Landscape Stress - Number of Reserves				-Ecological footprint -Green Buildings -Percentage of Ecosystems at Risk
Sustainable Development Goals Index (2017)	Sachs et.al. (Bertelsmann Stiftung and Sustainable Development Solutions Network)	PM2.5 in urban areas	-Access to improved water -Access to improved sanitation -Freshwater withdrawal -Imported groundwater depletion		- Marine sites, mean protected area -Biodiversity - Clean waters - Fish stocks overexploited or collapsed - Terrestrial sites, mean protected area - Freshwater sites, mean protected area - Red List Index of species survival - Annual change in forest area - Imported biodiversity impacts	-Access to electricity -Access to non-solid fuels (%) -CO2 from fuels &electricity -Renewable energy in final consumption	-CO2 emissions from energy -Imported CO2 emissions, tech-adjusted -Climate change vulnerability -Effective Carbon Rate		-Improved water source, piped

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Table 2.5 (continued) : Sustainability indices, parameters, and indicators identified through different policy documents and projects.

Project name	Institution	Air Quality	Water Resources & Quality	Soil Quality	Biodiversity	Energy	Climate	Waste	Other
European Green City Index (2009)	Siemens	CO2 emissions CO2 intensity CO2 reduction strategy NO2 emissions Ozone emissions PM10 emissions SO2 emissions Clean air policies	Water consumption Water system leakages Wastewater treatment Water efficiency and treatment			Energy consumption Energy intensity Renewable energy consumption Clean and efficient energy policies		Municipal waste production Waste recycling Waste reduction and policies Green land-use policies	- Environmental governance -Transport -Buildings
SOLUTIONS (2010)	Echenique et.al.	CO2 emissions NOx emissions VOC PM10				Transport energy Residential buildings energy Commercial buildings energy			
UK Sustainable Cities Index (2007)	Forum for the Future	the annual average of particles	Percentage of rivers					Wastewater collected per person	Ecological footprint

Project name	Institution	Air Quality	Water Resources & Quality	Soil Quality	Biodiversity	Energy	Climate	Waste	Other
PLUREL (2010)	FP6 Project Consortium	-CO emissions -HC emissions -NOx emissions -Heavy metal emissions		Soil sealing	Endangered bird species				-The density of natural habitats -Landscape interspersion -Landscape patchiness -Landscape fragmentation
Triple Value Framework of the Office of Research and Development (ORD) (2012)	Fiksel et. al. for the US Environmental Protection Agency (EPA)	Different type of classification based on four categories: Adverse Outcome (AOI)—indicates destruction of value due to impacts upon individuals, communities, business enterprises, or the natural environment. Resource Flow (RFI)—indicates pressures associated with the rate of consumption of resources, including materials, energy, water, land, or biota. System Condition (SCI)—indicates the state of the systems in question, i.e., individuals, communities, business enterprises, or the natural environment. Value Creation (VCI)—indicates the creation of value (both economic and well being) Through the enrichment of individuals, communities, business enterprises, or the natural environment.							

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2.1.2.1 Air quality

Air quality is closely correlated with land-use types and related activities such as consumption of fossil fuels required for electricity production, transportation, industrial processes, and household heating and agriculture and waste treatment (EEA, 2008). Thereof quality of air is heavily dependent on human activities on the ground and meanwhile, it has an impact on human health and daily life as well as ecological components (Url-1, Url-2). Air pollution has a negative impact on ecosystems, specifically based on sulfur and nitrogen emissions and ozone as it influences ecosystems' capability to operate and grow. Sulfur dioxide and nitrogen oxides emissions cumulate in water, on vegetation, and in soils as "acid rain", hence increases their acidity that have negative effects on both flora and fauna which ultimately hinders ability of ecosystems to maintain and sustain their services, such as nutrient cycling, carbon cycling, water provision and quality on which the planet and all biological assets depend upon (Url-3).

Literature suggests that air quality has a significant impact on forest ecosystems due to a reduction in the reproduction of forest trees because of air-contaminants degrading the reproduction cycle and nutrient recycling (Url-4). Forest ecosystems accumulate nutrient elements where these elements interact with each other and other organisms continuously (Smith, 1990). The emissions of nutrients from organic components are carried out by a variety of soil microbes and fauna via complicated procedures of dissolution and mineralization activities in which the proportion of litter decomposition influences the capacity of nutrient release (Witkamp and Ausmus, 1976). As those nutrients are mostly finite, the ability of decomposition has control over the ratio of production in forests (ibid). Thereby, any significant reduction in the rate of decomposition emerges the potential of affecting forest growth (Smith, 1990).

Due to its significant relation with land-use and human activities, air quality is one of the main concerns in spatial planning. For example in Planning Practice Guidance established in the United Kingdom; it is stated that spatial plans can dominate air quality in various ways, based on proposed development functions and locations, and how sustainable transport is promoted in these plans. Therefore, in the planning process, it is important to consider the requirements or limitations of new development

types regarding air quality. The Guidance also indicates that in order to sustain and ensure local air quality trends, spatial plans need to consider:

– how a number of small scale developments can have a cumulative impact on air quality as well as the impacts of larger developments;

– the impact of specific point sources of air pollution and

– how new developments would be suitable in locations to avoid unmanageable risks derived from air pollution

This could be achieved by defining precautions for compensating the impacts on air quality sourced from new developments that must be incorporated with supplementary actions such as in an air quality action plan (Url-4).

Not only this guidance, but EU legislation is also quite informative about the importance of air quality and its consideration in the planning process. One of the basic documents in this regard is "Ambient Air Quality Directive-2008" that defines legal limitations for air components' concentrations in outdoor; which impact public health. In the USA, the Environmental Protection Agency (EPA), has a specific focus on air quality research and adjusts regulations to enhance the incorporation of air quality in the planning and development process.

Observations of pollutant emissions foster the concern to incorporate air quality parameters into planning. In 2009, Istanbul's air quality strategy document was published that relied on the specific observations which showed significant evidence that land-use routines have a certain impact on atmospheric composition. It can be clearly said that air pollutant's emission is completely anthropogenic (Table 2.6).

Table 2.6: Emission levels in Istanbul (LIFE Project, 2009).

	PM10	SO2	NOx	NMVOC	CO
Industry	7,630	58,468	9,394	117	1,714
Residential heating	13,631	10,983	7,014	18,351	123,510
Traffic	5,200	1,016	138,000	38,500	270,000
Total	26,461	70,467	154,408	56,968	395,224

Within this thesis research, in order to establish the link between air quality and land-use, a supplementary analysis is carried out benefiting from the data produced in the LIFE Project. In this study, detailed air quality maps based on different parameters are

created. In Figures 2.7, 2.8 and 2.9; the distribution of NO_x, SO_2, and PM_{10} can be seen.
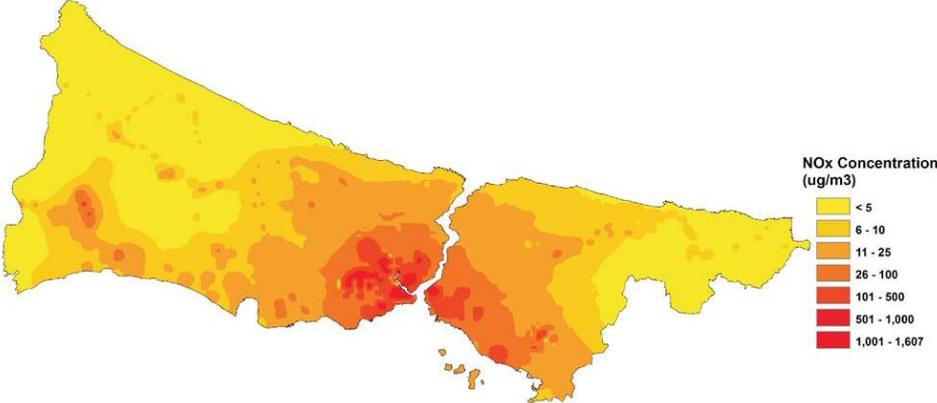
Figure 2.7: Modelled 2007 annual mean NO levels (in g/m^3).
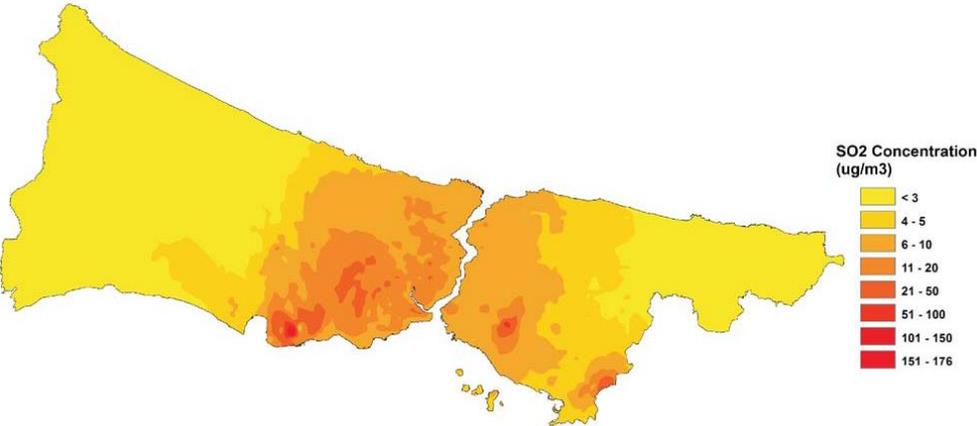
Figure 2.8: Modelled 2007 annual mean SO levels (in g/m^3).
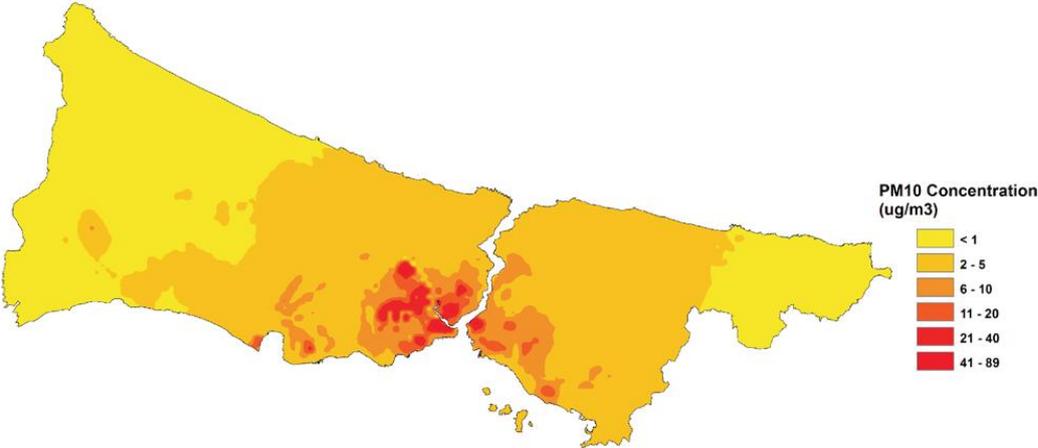
Figure 2.9: Modelled 2007 annual mean PM10 levels (in g/m^3).

After the retrieval of the air quality data above, it is intersected with the 2007 land-use data (gathered from Istanbul Environmental Master Plan-2009) of Istanbul using GIS

techniques. As a result of this intersection, it is clearly seen that urban (U) and industrial (I) uses definitely increase the pollutants in the air and such uses have a significant impact on air quality. On the other hand, Agricultural (A), Natural (N) and Degraded Natural (DN) areas (where natural green areas are under urbanization pressure) are at the acceptable quality levels that is quite below the levels caused by urban and industrial zones.
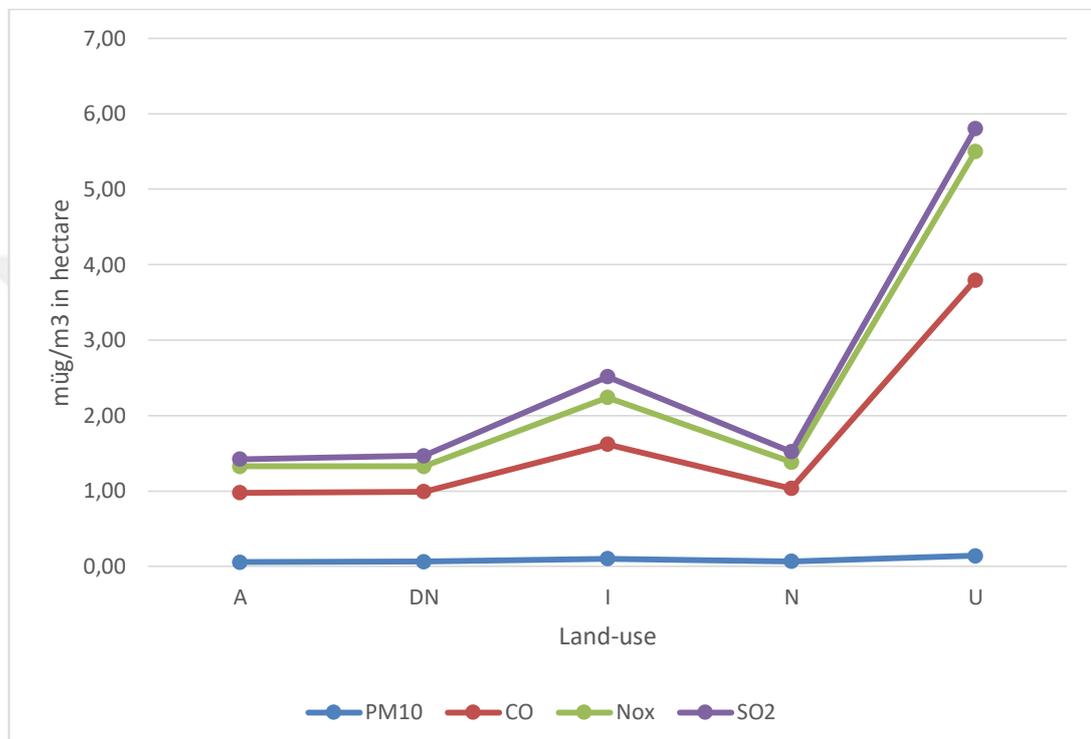
Figure 2.10: Relation between land-use and air quality parameters.

Based on the literature review summarized above and analysis carried out; it can be stated that air quality is strictly related to human interactions and land-use types (WHO/UNEP, 1992). In addition, it is certain that the increase of urbanization is one of the main sources of air pollution and therefore, the quality of air must be considered in the land-use planning process (ibid). While the types of land-use are a key determinant of atmospheric composition; on the contrary, air quality also has an impact on ecosystems' quality, human health and urban life. Thereof, it must be kept in mind that, an adverse impact on air quality means an adverse impact on ecosystems' quality, human health, and urban life and in most general terms ecological sustainability.

On the other hand, although air quality is one of the main indicators in most of the ecological sustainability assessments, measurement of air quality strictly relies on precise field measurements and interpretation of the measurement results. In addition,

even though there are policy documents that give insight on the importance of air quality within spatial planning; it is difficult to establish a concrete link between air quality and spatial plans which hinders the efficacy of the incorporation of air quality concerns in spatial planning. Therefore there is a significant benefit in developing tools and approaches that makes it possible to interpret the relation between air quality and spatial decisions.

2.1.2.2 Water quality

It is predicted that 96.5% of the water on earth consists of seas and oceans while 1.7% is groundwater, 1.7% is in glaciers in the Arctic and Antarctic circles (Khatri and Thyagi, 2015). A critical amount of water takes place in water bodies, and a very limited proportion (0.001%) is found in the air; which provides the basis of the water cycle with precipitation (ibid). As a result, only 2.5% of the Earth's water resources can be used by human and other biological systems, and 98.8% of this freshwater is kept within ice and groundwater; while less than 0.3% of freshwater takes place in rivers, lakes and the atmosphere (ibid). Therefore, water is placed at the center of the sustainable development process and has a crucial role in socio-economic well-being and ecosystems (WHO/UNEP,1991). It is critical for decreasing diseases at a global level and enhancing the health, welfare, and productivity of societies. It is the core of the provision and conservation of ecosystem functions and services for people; which increases the capability to adopt climate change that serves as the most important link among the climate, human society and the ecosystems (ibid). Thereof, the quality level of water has a crucial impact on the use of water by people and ecosystems and if water quality reduces, it can no longer be efficiently used. Thus assessing the water quality level and its correlation between anthropogenic activities is enlightening by means of providing insight on the future of water budget on earth.

Water quality assessment includes interpretation of the physical, chemical, and biological characteristics of water with respect to natural quality, anthropogenic effects, and desired uses (UNESCO/WHO/UNEP, 1996).In the United States of America, The National Stormwater Quality Database organizes data since the early 1990sgathered from nearly 200 municipalities bounded to EPA's "stormwater permit program" (EPA, 2013). Collected samples contain information of land-use type at the collection site, that makes it possible to compare water quality variations across land-

use types. Statistical analyses highlight significant differences in water quality parameters across land-uses almost for measured pollutants(ibid). According to the analysis results, open spaces show significantly low levels of pollutants whereas residential regions have the highest level of pollutant concentrations(ibid). In the same report released by EPA (2013), it is stated that highway drainage systems cause water pollution at the highest level due to the release of harmful solids, chemical oxygen demand, oil and grease, and ammonia. Moreover, it is estimated that roads and parking lots may cover 70% of the total impervious cover in cities and can act as an increasing factor for water pollution based on vehicle use (ibid).

Although it is hard to correlate within a gradient of development, variations along developed and undeveloped regions significant by means of water quality parameters. In a study that analyzed samples from five different catchments in California (USA) covering the storm events between the years of 2000 and 2005; it is found out that developed regions of the watersheds have a much higher concentration of copper, lead and zinc within water bodies. It is claimed that the differences were a conclusion of stormwater runoff from industrial areas in the developed watersheds (ibid). As a result, it can be clearly indicated that development in watersheds hinders the quantity, quality, and diversity of natural habitat within aquatic life (Booth and Bledsoe 2009).

In addition to surface water, development practices have an adverse impact on groundwater too. Although many studies do not have a clear distinction within their analyses to understand the effects of land-uses on groundwater quality, developed regions show a significantly higher level of pollutant concentrations (such as calcium, sulfate, nitrate, pesticides, etc.) than less developed areas (Trojan et.al., 2003). Another study on the influences of land-use on water quality within an aquifer in east-central Minnesota, researchers discovered that cumulative dissolved solids (such as sulfate, potassium, and calcium) in groundwater are much higher in urbanized residential, commercial and industrial areas than undeveloped rural areas where agricultural development is more frequent and residential use is limited. Samples gathered over a four-year period proved that when a rural/undeveloped area transforms into residential or industrial water chemistry changes accordingly (ibid).

In summary, a certain fact arises from the literature that is urbanization and related activities reduce water quality and threaten ground-water quantities as well (Khanet.al, 2017; Kandler et.al, 2017; Pullanikkatil et.al, 2015; Khatri and Thyagi, 2015). It is also

known that different land-use types have different impacts on water quality and quantity. Observations show that while forest areas increase the absorption of rainfall and hence enhance water quality by reducing surface runoff; urban areas or agricultural areas tend to cause more runoff and hence pollution (Camara et.al, 2019; Cheng et.al, 2018; Yu et.al, 2016; Chen et.al, 2016). Although the level of impact depends on the site-specific characteristics; a correlation between water quality and land-use is significant (Giri and Qiu, 2015; Pratt and Cheng, 2011). On the other hand, it is hard to state that it is practical to set up an analytic relation between land-use type and water quality components. Thusly, establishing a link between those components and land-uses proposed by a spatial plan is seemingly difficult which requires a wide range of data on water parameters and knowledge to analyze the correlation.

2.1.2.3 Soil quality

Along with air and water quality, soil quality is one of the three tiers of environmental quality (Andrews et al., 2002). While quality of water and air are closely related and identified mainly by the degree of pollution (Carter et al., 1997; Davidson, 2000); soil quality addresses not the only level of pollution but also the capacity of soils to provide benefits to biodiversity, promote the health of flora and fauna and sustain ecological productivity (Doran and Parkin, 1994, 1996). In this regard, many assessments of soil quality comprise both environmental parameters and measures of crop production ability. Parr et. al. (1992) defines soil quality as *"the capability of the soil to deliver healthy and nutritious products sustainably for the long-term and to improve human and fauna well-being without harming natural habitats"*. In another definition, by (Arshad and Coen, 1992) soil quality is described as the "*ability of a soil to conserve a viable environment along with the continuation of the capability to absorb, deposit and recycle water, minerals, and energy for production of crops efficiently"* (Arshad and Coen, 1992). A report of the National Academy of Sciences (NAS) identifies soil quality as "the capacity of a soil to carry out its three main functions: to operate as the main input to crop production, to water regulation and to function as an ecological filter (1993).

Soil quality is more complex to assess than air and water quality since soil has solid, liquid and gaseous phases and moreover, soils often respond slowly to changes in land-use and management, and hence it is harder to sense the changes in soil quality before

irremediable effects occur than for the quality of water and air (Nortcliff, 2002). Therefore, a critical step of soil quality assessment is the identification of the critical soil attributes that represent the capability of the soil to provide services and can act as a proxy for soil quality (Bünemann et al., 2018).

As seen in many similar studies, indices are used in the measurement of soil quality and comparison of quality level between entities. Parr et.al (1992) suggest that parameters such as soil characteristics, production capacity, ecological factors, health (human/animal), erosion and biodiversity must take place in a soil quality index. Many of these factors, are complicated indicators themselves but may be important to understanding the whole aspects of soil quality (ibid). Based on a detailed literature review, Bünemann et.al. (2018) summarizes26 different indicators that are used commonly within 65 different soil quality assessment studies. In this summary (Figure 2.11), indicators are categorized in biological, chemical and physical indicator sets. In the same research, it is highlighted that mostly used indicators are determined as total organic matter/carbon and pH. These indicators are followed by available phosphorus, various indicators of water storage and bulk density; which are considered more than half of the reviewed researches. More than 40% of the indices include the indicators of texture, available potassium, and total nitrogen. On average, 11 indicators are offered to represent soil quality based on their commonness and efficiency to be gathered from a practical point of view (Bünemann et.al., 2018).
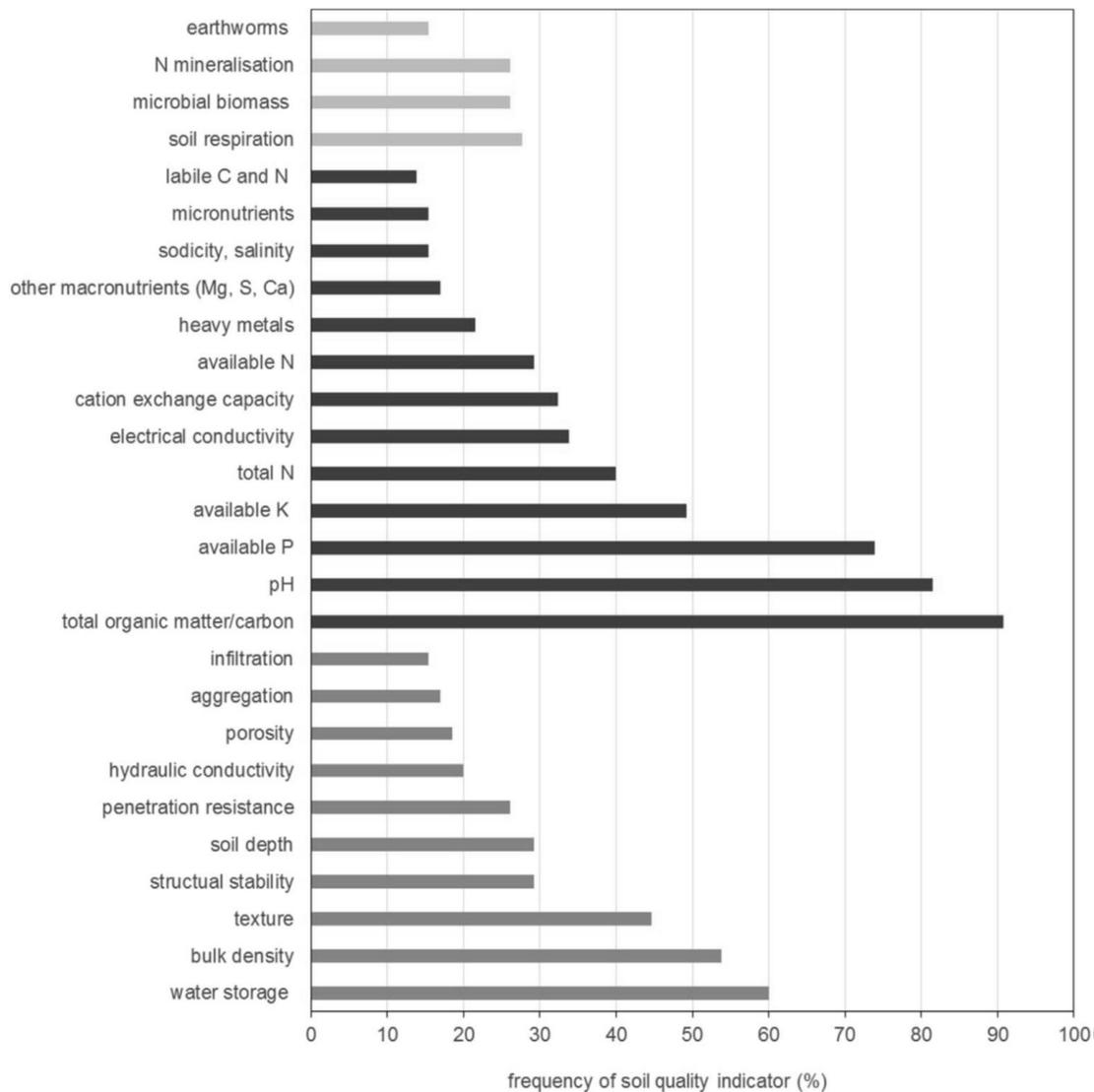
Figure 2.11 : Soil quality indicators in Bünemann et.al. (2018).

Research on soil quality proves that soil components to define soil quality are almost acknowledged upon but they require precise measurements and observations (Bünemann et.al, 2018). It is also known that soil parameters are closely correlated with the type of land-use and changes of land-use type such as from forest to agriculture or from pasture to urban are processes that degrades the properties and components of soil (Gonzalez et.al, 2014; Tsadila et.al, 2012; Ambatziset.al., 2004). Lack of soil management in the spatial development process can sharply worsen large amounts of land, which often becomes a primer risk factor to rural well-being in many countries. Contrarily, the impact of land-use changes on soil can emerge without any sign that leads decision-makers to misinterpret the consequences and hinders them to act responsively in a timely manner (Gonzalez et.al, 2014).

As a result, since soil components play a vital role in enhancing crop production and greenhouse gas emission (Göl, 2009), open lands and soils must be considered as critical assets that foster environmental sustainability within the land-use planning process. Thereof, a possible impact on soil quality due to land-use change offered by a spatial plan must be taken into account properly. It is also widely acknowledged that urbanization has a negative impact on soil quality by degrading soil and occurring soil loss in nature. Nevertheless, even though urbanization's impact on soil quality is obvious, establishing a solid linkage between land-use functions and soil parameters relies on detailed measurements and observations that may be costly and time-consuming.

2.1.2.4 Biodiversity

Biodiversity, also named as biological diversity, is basically interlinked with the variety of life found in a place on Earth or, often, the total variety of life on Earth (Url-6). In more detail, it is explained as the diversity of living organisms within land, seas, oceans, and other aquatic ecosystems and the ecological systems of which they are a part; including the alternation in genetic, phenotypic, phylogenetic, and functional attributes, as well as differences in affluence and arrangement over time and space within and among species, biological communities and ecosystems" (UN Convention on Biological Diversity, 1992).

World Conservation Union (IUCN) indicates that about 14% of all world's bird species and 25% of its mammals are under the risk of extinction (2019). Moreover, between half and one percent, the world's tropical forests are being lost each year; one-third of the mangroves have been demolished between the early 1980s and 2000s and amphibian population have degraded approximately 80% in 50 years (FAO 2001; Achard et al 2002; Valiela et. al. 2001; Houlahan et. al.; 2000; Crane, 2003). According to the latest findings, forest degradation is a major global threat to biological diversity and to ecosystem services (FAO, 2018). Although rates of loss have slowed down and even changed in favor of forest areas in some regions, global forest quantity continues to decrease due to transformation to agriculture, with illegal logging, fires and fuelwood extraction (ibid).

Losses of biological diversity are mainly caused by human population growth and by unsustainable trends of resource depletion, advocated by improper economic

structures and actions that increase short-term gain but compromises from capacities in the long-term (Raven, 2002). In accordance, urbanization scales up to the loss of biodiversity and due to the tendency of ongoing urbanization; the adverse effects on biodiversity will probably continue (Balfors et.al, 2013). There is significant scientific consensus that if proper actions and measures are not taken against pressures such as fragmentation, loss, and degradation of natural resources, overuse of flora and fauna and climate change; it is inevitable to lose the biodiversity on earth in an extraordinary rate that has never been since the emergence of modern types of ecosystems more than 40 million years ago(May et. al., 1995; Pimm & Askins, 1995; Myers & Knoll, 2001).

Biodiversity has the potential to present invaluable socio-economic, scientific, technical, and socio-cultural functions that increase the services that rely on diversity within and among whole living organisms (Crane et.al., 2003). The viewpoint on sustainability requires that these services must continue to be available to future generations as well and therefore biodiversity conservation is an essential aspect of sustainability (ibid).

Therefore, it is critical to embed knowledge of the spatial ecology and biodiversity into planning implementations in order to establish a foundation for taking right decisions on spatial planning and administration to avoid further biodiversity loss resulting from urbanization (Karen et al., 2012; Aronson et al., 2014).

In order to succeed in the incorporation of biodiversity concerns into planning and development procedures, biodiversity must be understood in detail spatially and it must be quantitatively known. Although there is an abundance of GIS-based spatial ecological models that aims to set up the relation between biodiversity and land-use change; these models mostly focus on different levels and scales; they require classified remote sensing data, field research, and detailed knowledge on habitat types (Balfors et.al., 2013). Thus, the core challenges within this process emerge as lack of knowledge on species, geographical areas, biomes and ecosystem services, lack of availability of existing approaches to be used within policy decisions (Crane., 2003) and complexity and variety of these models (Balfors et.al., 2013).

Consequently; it is observed that although the main aspects of biodiversity (extent of habitat, ecosystem processes, distribution of species and population size of species) are agreed upon; retrieval of data for representing these aspects are mostly complex

and/or assessments require a certain level of scientific and technological engagement. This is critical since urbanization has driven land-use changes threatens biodiversity in a permanent way and in order to avoid future degradation; applicable approaches to establish the relationship between biodiversity and land-use change must be developed.

2.2 Sustainable Land-use (Spatial) Planning

The way how land is used is one of the main factors of environmental change, as the policies of land-use effects fundamental resources within the landscape (Gonzalez et.al, 2014) and changes in land-use often have a negative impact on ecosystems (Tezer et.al., 2018, Terzi et.al., 2019). Therefore spatial planning is mainly concerned with spatial impacts of the decision- making process based on sector policies and actions in public and private sectors (Kopperoinen et.al., 2013). It aims at considering and coordinating these impacts in a manner that enables spatial development to be sustainable (Nadin, 2006). Thereof, sustainable approaches in land-use planning are fundamental for ensuring the sustainable management of land. Food and Agricultural Organization of United Nations uses the term of sustainable land management (SLM) and defines it as "*the management of land resources, including ecosystems, flora and fauna, for the production of assets to fulfill evolving needs of humankind, while at the same time assuring the long-term production capacity of the resources and the protection of their ecological services*". The efficiency and sustainability of a land-use function are identified by the interaction within and among resources, climate characteristics and human interventions. Specifically, in the face of climate change, deciding the proper land-use type for a given area under specific socio-economic conditions and adoption of sustainability concerns are critical for reducing the loss of biodiversity, natural habitats, land degradation, guaranteeing the sustainable use of resources and increasing resilience of our environment. Thereof, the success of sustainable land-use and management practices is decisive to ensure the sustainability/resilience or degradation/vulnerability of land resources (FAO, 2018). The motivational background for the integration of sustainability term into land-use planning and land-use management processes can be seen in the urban growth in the last decade. Since 2007 more than half of the world's population has been living in cities and by 2030, the urban population is estimated to reach 5 billion (UN, 2012). As

a result demand on land resources increases in correlation with the urban population and therefore the most basic issue in this urbanization process will be to manage resource requirements (Vega-Azamar et. al., 2015).

In this regard, the first international level emphasis on the consumption of resources was made by UN's "Agenda 21" declaration (1992) that highlights the importance of access to resources and states that right of access to the resources such as land, air, water, and energy is the foundation of our humanity. Due to the expansion of urban areas the access to resources gets harder since residential, industrial and commercial functions take place of ecologically sensitive and productive open spaces. Overuse of these open spaces and conversion of them into urbanized areas are the main factors of environmental degradation (UN, 1992). Meanwhile according to UN's Sustainable Development Goals Progress Report (2015) geographic borders of cities grow in line with the urban population; nevertheless it is also noted that in the 2000-2015 period, areal growth rate of cities is larger than population growth rate which indicates urban sprawl that results as the re-functioning and consumption of rural lands. The most significant characteristics of urban sprawl are an increase in transportation distances, depletion of lands and fragmentation of natural ecosystems that minimize the benefits provided by nature (Kışlalıoğlu and Berkes, 2010). As a result, due to dependence of ecological equilibrium on the dimension and spatial use types of the cities (Orishimo, 1982), in order to sustain the environmental health and natural resources, ecological concerns must be considered in determining the spatial use types of the cities or in other words ecology driven spatial planning must be in place (Chen et.al., 2015). Ozcan (2016) transfers from the literature that ecology-oriented spatial planning approach that determines the scale and context of urban development based on ecological resources and values; is the constituent of sustainable land-use planning (Van Geenhuisan and Nijkamp, 1994; Fawcett-Thompson, 1996; Diepen and Voogd, 2001; Alshuwaikhat and Nkwenti, 2002; Tezer et.al., 2018, Terzi et.al., 2019). Therefore, while incorporating ecological aspects into spatial planning, urban systems must be handled more comprehensively and correlation between urban functions and ecosystem must be addressed clearly (Pauleit and Duhme, 2000). However, there is a certain lack of analytical and quantitative approaches that aim at assessing the impact of land-use on ecological sustainability and it is hard to find a consensus within these approaches (Petit et.al, 2001).

In general, the land-use planning process follows the steps of environmental, geological, socioeconomic, etc. data acquisition, analysis of these data, synthesis of the analyses in line with plan vision and determination of land-use types. Yet environmental data is mostly handled as a land cover instead of a living ecosystem, which causes the neglection of actual importance and value of ecosystems and leads to excess of ecological limits and extinction of resources. In this regard, maintaining the services and benefits provided by ecosystems at an optimum level is the fundamental component of ecological sustainability (Millennium Ecosystem Assessment, 2005) and in accordance; changes in land-use have a significant impact on ecological sustainability (Costanza et.al, 1997). Within the sustainability context, the impact of urban development on ecological sustainability is directly related to the ecological carrying capacity of the implementation area. Thus, for evaluating the environmental sustainability performance of spatial plans, carrying capacity of ecosystems and benefits from these ecosystems must be considered. In other words, for achieving rational planning decisions it is critical to assess the ecological impact that a plan can create on the implementation area. In order to apply a holistic assessment, both sides of the urban functions must be taken into account. While it is a well-known fact that cities have a negative impact on ecosystems (Colding, 2011), cities also have the potential to serve as ecosystem providers with natural and semi-natural habitats. As a result; it is possible to analyze the ecological sustainability of urban development within a framework where benefits and impacts of urban functions are handled in integration (Wiggering et.al., 2003).

As a result, in line with the overall outlook in sustainable land-use planning literature; the ES approach can be used as an efficient tool for evaluating the interaction between spatial plans and ecosystems by allowing to correlate a land-use function and its ecological benefits (Sumarge and Hien, 2015). Considering ecosystems' functions, benefits and products in planning procedures will eventually provide more rational results by means of ecological sustainability (Groot, 2006). In this regard, there is a certain requirement for embedding ES oriented planning into the urban development process for securing the sustainability of resources and taking control of ecological degradation (Perminova et.al., 2016). In EU level, there are various frameworks developed for setting targets and performance indicators for urban sustainability assessments but there is a lack of universal and acknowledged approaches that can be

adapted into spatial planning process as well as a lack of agreed common, easily adaptable targets and performance indicators for nature-based solutions, urban green infrastructures, biodiversity and ecosystem services that cover planning, management, governance and performance (EC, 2018).

2.3 Ecosystem Services (ES)

Spatial planning arranges how land is used, which also means a change in land-use and ecosystem structure as well through converting land and water areas for new purposes (Kopperoinen et.al., 2013). Thusly, changes proposed by plans result in impacts on ecological processes. As seen in chapter 2.2, there is a significant relationship between land-use and ecological sustainability components but on the other hand; detailed data or measurements are required in order to execute and impact assessment. The Millennium Ecosystem Assessment (MA, 2005), as well as many other studies that followed, highlighted the importance of integrating ecosystem services (ES) into strategic decision- making, so that the impacts of development practices on ecosystems and on their benefits and functions, can be regarded as the most appropriate phase of planning (Genelleti, 2013).

Researchers from different disciplines have discussed the ES concept for decades but the notion is mostly acknowledged and advocated by Millennium Ecosystem Assessment (MA) in the early 2000s.EPA defines ES as the benefits provided by ecosystems to human well-being which are estimated based on anthropogenic values and can be regarded as the direct and indirect socio-cultural, economic and environmental functions provided to humankind and represents the complexity between all kind of living organisms and their natural living habitat (2016).

In MA, ES is divided into four main categories as provisioning, regulating, supporting and cultural. Provisioning services include benefits such as the production of water, wood, and timber; regulating services include benefits such as the mitigation of hazards and regulation of air quality; supporting services include functions such as crop pollination and nutrient cycles; cultural services include functions such as educational, aesthetic and recreational benefits (Figure 2.10).
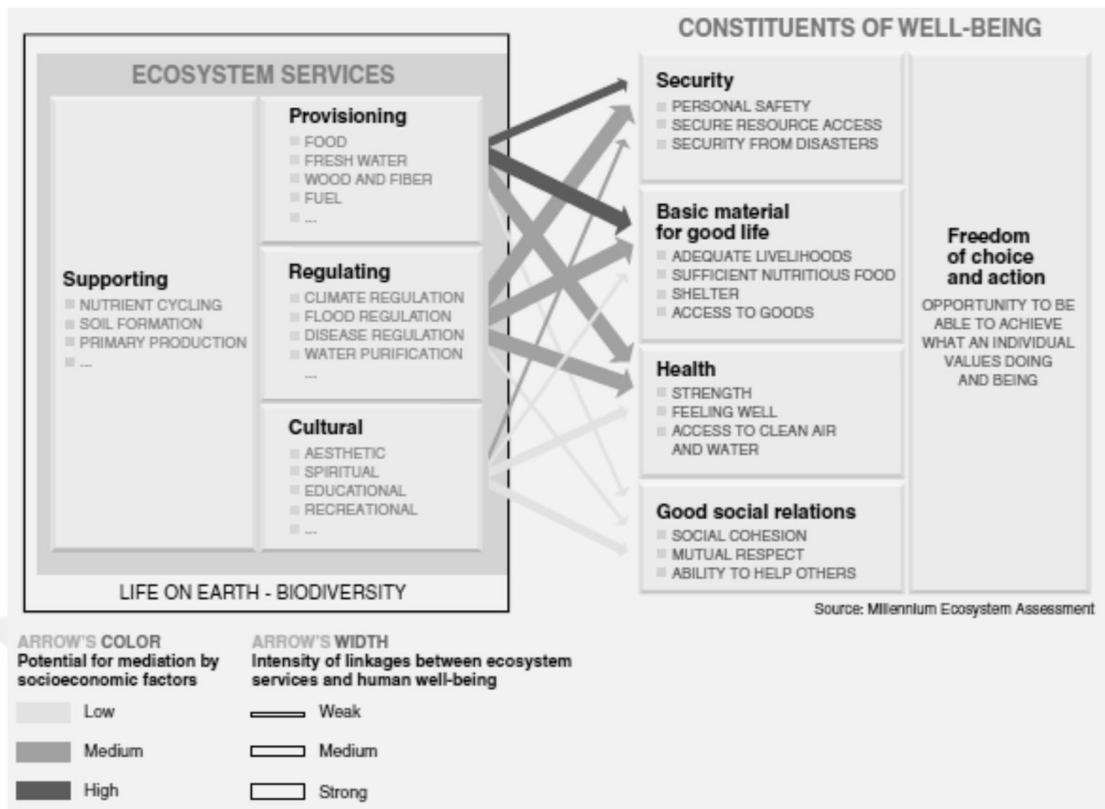
Figure 2.12 : Millennium Ecosystem Assessment framework (MA, 2005).

Meanwhile, newer approaches to defining ES have been established after MA such as The Economics of Ecosystems and Biodiversity (TEEB) and Common International Classification of Ecosystem Services (CICES) offering different types of classifications. CICES is the latest ES framework and it is widely adopted in many studies. CICES has been designated to help estimate, evaluate for, and assess ecosystem services. In CICES, ecosystem services are defined as the benefits that ecosystems provide to human well-being and the values and assets that human acquires from them. These benefits are conceptualized in the motto of 'what ecosystems do' for people (Haines-Young and Potschin, 2018). CICES depends on the concept of the so-called "cascade model" that draws out the overall approach of the classification (Figure 2.11). Haines-Young and Potschin state that CICES focuses on *"final ecosystem services"* that are the benefits humans gather from ecosystems, directly or indirectly affect the well-being of people.
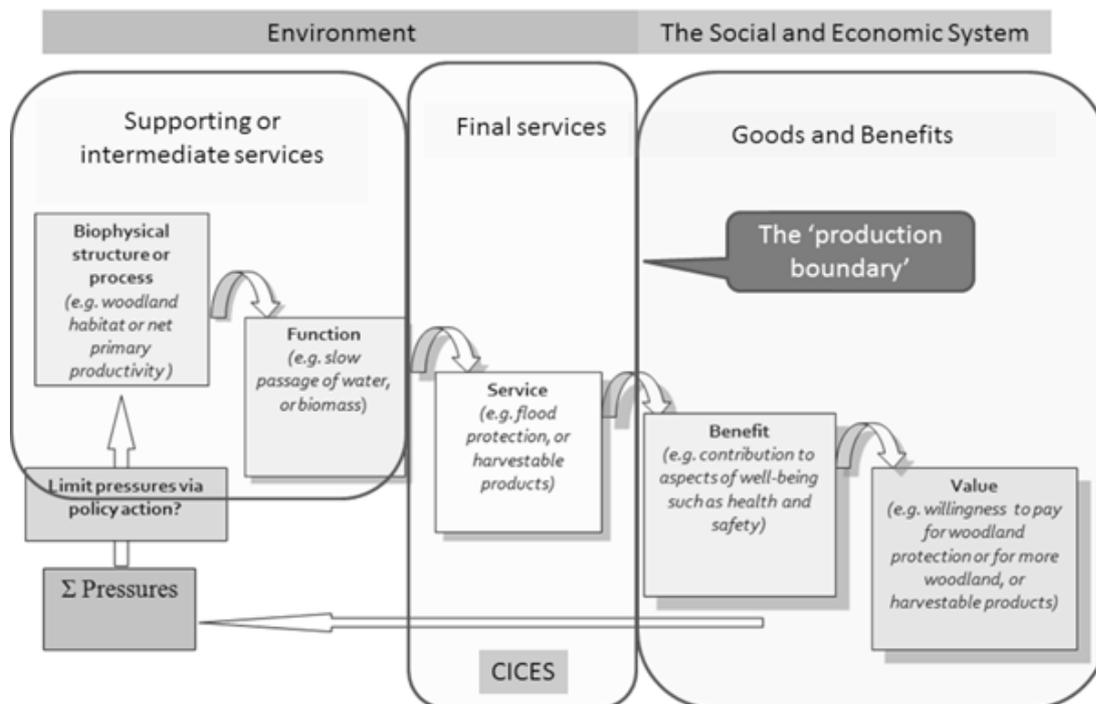
Figure 2.13 : Cascade model in CICES by Haines-Young and Potschin (2018).

Similar to MA (2005), CICES also defines final ecosystem services in three categories as provisioning, regulating and maintenance and cultural services. Provisioning services include all types of nutritional and non-nutritional material provided from ecosystems as well as abiotic services such as water. Regulating and maintenance services describe how living organisms can enhance and moderate the environment along with abiotic assets. Cultural services meanwhile, involves all the non-material, and spiritual outputs of ecosystems that have a positive impact on the physical and mental well-being of humankind.

Within this context, ES includes all the basic elements of an ordinary impact assessment of a spatial plan: ecological, social, cultural and economic impacts derived due to land-use change (Kopperoinen et. al., 2013). Hereof, one of the most efficient and widely used approaches to evaluate the possible impacts of plans is the ES mapping approach (Burkhard et. al, 2009, 2014; Jacobs et.al, 2014).

Based on the aim of mapping and spatial context, ecosystem mapping is an act of a spatial representation of ecosystems relying on an agreed ecosystem typology (EEA, 2015). Although ES mapping is used as the basic tool of ecosystem assessment, it may also include more detail and give information on the state of the ecosystem's quality based on the monitoring outputs (EC, 2013). Mostly used approaches in ES mapping

differ in two ways: typological and regional (or their mix use). The typological method splits natural habitat into smaller ecosystem types where the same classes can occur in different locations. In the regional method, ecosystems are defined as unique entities that belong specifically to a particular region. Since the ES mapping approach has to be suitable to be used as an input in the decision-making process, it has to rely on data that may not be available in most cases. Lack of proper datasets leads practitioners to the aggregation of currently available datasets and use proxy spatial data that defines the biophysical structure on the land and aquatic ecosystems in the most sufficient way. In this regard, ES mapping must target to enable quantitative and analytical aspects of the states of ecosystems including their extent, distribution and content as well (ibid). In "Mapping and Assessment of Ecosystems and their Services-MAES" adopted by EU, for practical purposes, mainly sourced from lack of data availability, and because of the strong relation to the Copernicus land monitoring services of EU, ecosystem mapping is based on the EU Biodiversity 2010 Baseline approach (EEA, 2015). This implies that CORINE Land Cover (CLC) classes as monitored in Copernicus are converted into ecosystem types for the purposes of MAES, in the most appropriate way to represent large-scale ecosystems, and integrated with information regarding the respective ecosystem. This aggregation relies on a detailed expert review of interactions between land cover data and habitat classes to assure consistency between different methods (EC, 2013).

ES maps are solid outputs to bring ES into implementation and decision making level since maps can effectively represent complicated spatial information in a visual way. Thereof users often tend to look at maps and to identify maps' content and practical suitability for their own purposes. Thus, ES maps are also beneficial for raising awareness about how ecosystems can provide goods, regulate nature, give information about ecosystem interaction and enhance environmental quality. Moreover, maps can be used as decision support tools in spatial planning and environmental management under the conditions that ES maps are based on accurate, precise and concrete data on ES supplies, flow, and demand (Müller et.al., 2017).

In this regard, ES has a great capacity to become a primary mechanism for policy and decision making at global, national, regional and local scales. Possible uses vary from sustainable use and consumption of natural resources, spatial use arrangement,

environmental preservation, protection and restoration of nature, spatial planning, and disaster risk reduction to climate change adaptation (Maes et.al., 2017).

In one of the aforementioned studies in literature review, namely "SENSOR (Sustainability Impact Assessment: Tools for environmental, social and economic effects of multifunctional land-use in European regions)" project; Helming et.al (2008) developed a novel approach to evaluate the impact of land-use changes on land-use sustainability; in which "land-use functions" concept constitute the backbone of their methodology. In the SENSOR project, land-use functions are defined as the services supplied by different types of land-uses that represent the most relevant economic, environmental and societal capabilities of a given region (Perez-Soba et.al., 2008). In the SENSOR approach, although land-use functions concept is considered as more holistic and applicable than ES; proposed land-use functions are closely related to ES. The environmental land-use functions are described as the provision of abiotic resources, support and provision of biotic resources and maintenance of ecosystem processes (Perez-Soba et.al., 2008) that are exactly the same notion as in CICES framework and those indicators are used to evaluate the environmental aspect of sustainability impact due to land-use changes.

As a result, in spatial planning and urban development; ES concept provides great advantages for practitioners and decision-makers for assessing and understanding of sustainability from a holistic point of view that involves regulating, provisioning and cultural aspects which enables the evaluation of the value of our nature as a supportive backbone in policy-making process (Frank et.al., 2017).

2.4 Overall Evaluation of Literature Review and Answers to Research Questions

Literature review shows that the sustainability phenomenon is dominating the field of development processes in the world as well as spatial planning discipline. Numerous efforts aim at assessing the sustainability level of countries, regions or cities and all of them have various aspects based on the subject area. Most similar aspects of these efforts are to carry out assessments based on indices and in ecological means, a dependency of these indices on air, water, soil quality and biodiversity level of the study area. It has been observed that sustainability indices mostly require detailed data, specifically for analyzing the level of sustainability components such as air, water, and

soil quality. On the other hand, although sustainable spatial planning emerges as the main axis for the evolvement of planning routines, there are certain gaps between ecological concerns and planning outcomes, which result in the unsustainable development of cities and regions. The main reasons behind this are the lack of data required for sustainability assessments and difficulties to correlate sustainability components with spatial plans. Thus, it is obvious that there is a need for proper tools that leverage the incorporation of ecological aspects into planning procedures.

Since it is mostly not feasible or easy to find relevant data on air, water, soil quality and biodiversity parameters of "ecological sustainability", a more generalized but still effective method representing the ecological sustainability process must be used within spatial planning. Literature findings suggest that ES can play such a role and can provide the transition from ecological aspects to spatial decisions. Nevertheless, ES context is set up with an anthropogenic perspective and as ES definition suggests; ES is necessary for "human" well being. Therefore, in order to use ES components for representing the ecological sustainability of spatial plans, the components that can also respond to the well-being of our nature must be taken into account. As stated previously, ES is mainly classified into three components like provisioning, regulating and cultural services in the CICES framework. Within these tiers, regulating services can be directly related to an ecological pillar of sustainability context since regulating ES mainly contains the enhancement of air, water, and soil quality and hence ensures biodiversity.

Sub-components of regulating services also foster this statement by focusing on detailed benefits provided by ecosystems for improvement of the quality of the environment. In CICES framework, regulating and maintenance services are epitomized by examples such as sustainable disposal of wastes; reduction in respiratory disease, low noise environment, visual amenity, sustainable populations of useful or iconic species that contribute to a service in another ecosystem, maintenance of soil quality; legumes used to increase/maintain N-levels in soil, reduced damage costs nutrient runoff from agroecosystems, climate regulation resulting in avoided damage costs and increased thermal comfort in cities. A matching diagram between based on the CICES regulating and maintenance services with ecological sustainability components is given in Figure 2.14.

| REGULATING SERVICES IN CICES FRAMEWORK | ECOLOGICAL SUSTAINABILITY COMPONENTS |

Mediation of wastes or toxic substances of anthropogenic origin by living processes

Mediation of nuisances of anthropogenic origin

Regulation of baseline flows and extreme events

Lifecycle maintenance, habitat and gene pool protection

Pest and disease control

Regulation of soil quality

Water conditions

Atmospheric composition and conditions

Air Quality

Water Quality

Soil Quality

Biodiversity

Figure 2.14 : Regulating ES & sustainability indicators matching the diagram.

Under the guidance of research questions given in the introduction section, the literature on sustainability research, spatial planning, and ecosystem services show that:

RQ1: Within spatial development context; how is ecological sustainability defined and measured within acknowledged frameworks and what are the main components of ecological sustainability?

Finding: There are various efforts in assessing the level of sustainability within a given area or region. These efforts mostly rely on indices developed for comparing those given areas (cities, countries, etc.) but these comparisons are mostly executed in a relativistic manner and therefore they do not reflect the actual state of the ecosystem

and disregard finite nature of resources. Within these assessment methods; the ecological aspect of sustainability is mainly based on air quality, water quality, soil quality and level of biodiversity parameters. These parameters are often measured based on actual observations including biophysical characteristics of those parameters such as concentration levels of particular elements within air, water or soil. It is also found out that most of the current sustainability indices are generated with an ex-post approach instead of ex-ante; in other words, they are created in order to evaluate the current sustainability level of an area and compare them with each other.

RQ2: What is the current situation in considering the ecological concerns in the spatial planning process?

Finding: It can be claimed that although there are various methods and approaches to ensure ecological sustainability within spatial development; spatial planning and development processes do not perform well enough by means of protecting ecosystems and biodiversity. According to the UN, the population living in urban areas is expected to increase to 68% by 2050 (2011). Within this trend, an area the size of the United Kingdom (244.000 km^2) has been converted to built-up areas between 1990 and 2014 while 2.7% of semi-naturally vegetated land has been lost to other land cover types between 1992 and 2015 which equals to an area twice the size of Spain (OECD, 2018). Therefore, it can be stated that despite the achievements and efforts to understand the importance of ecosystems and the impact of development; there is no significant indicator proving that spatial development is in line with the ecological sustainability of our living environment. Moreover, in line with the RQ1's findings, sustainability indices do not serve exactly to make a healthy estimation on the impact that occurs due to spatial changes.

RQ3: How can ecosystems be utilized in order to understand the ecological sustainability level of spatial plans?

It is obvious that there is a significant need to develop efficient tools to evaluate the impacts of spatial use changes on ecological sustainability in order to reverse the ecological loss trend. Accordingly, the ES concept provides an applicable opportunity for planners and decision-makers to estimate the possible impacts of spatial planning on ecological sustainability. In order to use ES concept, "land-use functions" (Helming et.al, 2008) and "ES mapping" (Burkhard et.al, 2009) approaches can be adopted and

through this integration, a proxy for assessing the ecological sustainability performance of spatial plans can be generated.

3. METHODOLOGY OF THE RESEARCH

As stated in the findings of the literature review, various sustainability analysis/assessment tools and indicators have been developed to represent the ecological sustainability level of a selected entity, particularly cities. Criticisms on such indices indicate that in order to analyze ecological sustainability level of a given place, one must consider the finite characteristics of nature and ecosystems because nature cannot get beyond its limits and there is a carrying capacity for each ecosystem within but it is stated that sustainability indices mostly do not reflect the actual of the given areas but instead they make comparisons among them; which leads to a relativistic assessment. Another critical finding of the literature review is that sustainability indicators rely on specific metrics, measurements or indicators which are the outputs of the conditions in a given area; therefore they do not help to interpret the relation between sustainability level and causes that actually lead to measured outputs. As a result, spatial characteristics that is one of the most dominant determinants of sustainability state of a city, region or country is disregarded. In order to remove these gaps, developed methodology within this research relies on actual ES capacity of a spatial use type, which is assessed based on expert judgements, areal quantity, and level of fragmentation of these spatial use types. In this regard, this research draws on the ES concept and ES evaluation method as an interface of the sustainability assessment of spatial uses. The research's method builds upon the sustainability assessment of spatial plans that are the basic tools in spatial planning which shape the future of settlements and their environment.

To evaluate the ecological sustainability level of spatial plans, the fundamental principle of the method is to understand the provided ecological benefits and caused impacts by the spatial plans and calculating the difference between current spatial use and proposed spatial use. The estimated difference is enlightening by means of providing insight on a spatial plan whether it performs in favor of or against the ecological sustainability of the implemented area. This assessment provides great

benefits for the planners to evaluate their plan's level of impact on nature and lets them enhance their decisions for the well-being of nature.

As in sustainability assessments, the ES concept covers different aspects such as regulating, supporting, socio-cultural, recreational and provisioning services. In line with the aim of this research, only environmental aspects are taken into account and related ES are chosen to represent ecological sustainability level in spatial plans. Within ES frameworks, regulating ES plays an integral role which basically defines how ecosystems regulate nature's processes and how ecosystems provide environmental benefits. On the other hand, provisioning and socio-cultural services mainly focus on the provided goods and psychological/social benefits that ecosystems offer. For determining the relevant indicators; Millennium Ecosystem Assessment (MA) (2005), The Economics of Ecosystem and Biodiversity (TEEB) (2013) and Common International Classification of Ecosystem Services (CICES) (2013) are evaluated. In this study, CICES categorization (Table 3.1) is preferred since it is the latest version for ES classification schemes while embracing its predecessors and being widely adopted in many different studies.

As stated in section 2.4 where the compatibility of regulating services with ecological sustainability indicators is shown based on the literature review outputs; regulating ES can be used as a proxy to represent the ecological sustainability level of spatial plans. ES mapping approach has a fundamental role in this regard and it sets up the relation between spatial use and ES capacities of a given region.

As implemented by Burkhard et. al. (2009) and Jacobs et. al. (2014), the matrix model is an efficient ES mapping tool for relating spatial use/land cover and ES. The matrix model depends on the scorings derived from land cover's ES provisioning capacity that is mainly derived from expert judgements. Where available, the ES capacity values are enhanced with quantitative measurements regarding the specific ES type. For example, in order to evaluate food provision from a specific area, actual food production statistics from the related institution are gathered. Thereof a more accurate scoring can be done. A sample figure is shown in Figure 3.1 (Jacobs et.al, 2014) to give a better understanding of how spatial use types and their scorings are related.

Table 3.1 : ES categories Derived from The Biodiversity Information System for Europe (BISE)

ES Frame	ES Indicators								
MEA	Water purification and waste treatment	Erosion regulation	Water regulation		Air quality regulation	Pollination	Pest regulation	Disease regulation	Soil formation (supporting service)	Climate Regulation
TEEB	Water purification and waste treatment	Erosion prevention	Regulation of water flows	Moderation of extreme events	Air quality regulation	Pollination	Biological control		Maintenance of soil fertility	Climate Regulation
CICES (selected set)	Mediation by biota / Mediation by ecosystems	Mediation of mass flows	Mediation of liquid flows		Mediation of gaseous / air flows	Lifecycle maintenance, habitat and gene pool protection	Pest and disease control		Soil formation and composition	Atmospheric composition and climate regulation
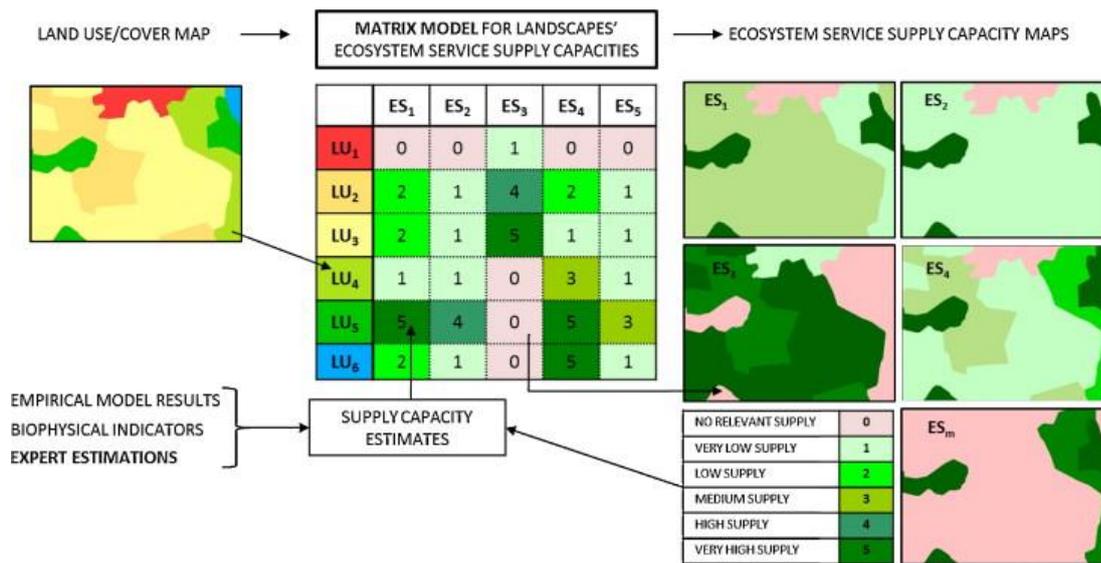
Figure 3.1 : Representation of ES scoring process (Jacob et.al, 2014).

As a result, a matrix is formed with two dimensions as can be seen in Table 3.2 (Burkhard et. al., 2009) where LC corresponds to "land cover" and "ES" corresponds to "ecosystem services".

Table 3.1 : Sample matrix derived to evaluate ES capacity of a land cover data.

	LC_1	LC_2	LC_3	LC_n
ES_1	5	3	5	3
ES_2	4	1	2	3
ES_n	3	1	2	0

The main aim of the matrix model is to estimate the ES provision capacity of a given area based on its land cover characteristics. Nevertheless, when it comes to the assessment of the ecological sustainability of a given area, the caused effects due to land cover must also be considered as well as the provided ES capacity.

Thus, in addition to the matrix model, it is assumed that while some of the land cover types contribute to ES capacity and ecological sustainability of a region positively; on the other hand, some of them have negative impacts. Land-uses and land cover such as forests provide air quality regulation, however, industrial land covers provide zero levels ES, but moreover, they may have negative impacts on air quality. Hence, such spatial uses must be taken into account as sources of impacts. A similar approach that overcomes the shortcoming of the matrix model was developed in the SENSOR Project (Helming et.al, 2011) where land-use is treated as an entity that provides

functions that may have positive or negative outcomes by means of ecological or socio-economical aspects. Helming et.al (2011) give examples from various studies that relate to ex-ante analyses of future land-use change scenarios based on a number of social, economic, and environmental indicators. In addition, they also precisely mention that for a more comprehensive sustainability impact assessment, there is a certain need of indicators that enable to link changes in spatial pattern and sustainable development (Helming et.al (2011). Helming et.al. (2008) define their approach as a combination of multifunctionality concept and ES concept, which aims at ex-ante assessment of sustainability induced by land-use change. Pérez-Soba et al. (2008) highlight the SENSOR project's multifunctionality approach by explaining that land-use functions have negative and positive significance with selected indicator sets where significance values vary between -2 and +2.

Since the matrix model's valuation is between "0 - 5" to examine the ES capacity (Burkhard et.al, 2009); the matrix must be expanded in order to include negative impacts caused by spatial uses. Therefore, this study employs the SENSOR approach combined with ES concept and defines matrix values between "-5 - +5" where negative values correspond to the impact potential of a spatial use type and they are presumed to reduce the ES capacity and overall ecological sustainability. Eventually, this matrix is designed to be used for ecological sustainability analysis of spatial plans and the method sets up the basic parameters for understanding the outcomes of spatial use types.

A fictional sample data is shown in Table 3.3 where EcS/LUT matrix is given where "EcS" corresponds to "ecological sustainability" and "LUT" corresponds to "land-use type".

Table 3.2 : Sample EcS scoring table

	LUT_1	LUT_2	LUT_3	LUT_n
EcS_1	5	3	-5	-3
EcS_2	4	4	-3	-3
EcS_n	1	1	-2	-1

Despite the scores provide insight on the potential on provision and/or impact of land-use types; an areal quantity of these land-uses must also be taken into account because their benefit or impact is directly related to their area sizes as well. The larger the LUT gets, the larger its service or impact level will be produced. Therefore, after the scores

are assigned, they are multiplied with their areal quantity that provides a unified unit for all indicators. But for the ease of mapping and viewing purposes, areas are converted in the "km^2" unit.

On the other hand, the multiplication of the EcS scores and area of a LUT does not give the exact level of its benefit or impact on ecological sustainability. Fragmentation of the land cover/ecosystems is also another important factor by means of ecological sustainability. Because it is known that, fragmentation of ecosystems has negative impacts on biodiversity and moreover in the long term it can lead to habitat loss and its functioning (McGarigal et.al, 2005). McGarigal et.al also states that changes in scope and interconnectedness of ecosystem conditions have an impact on many processes that affect "the behavior and spatial habitat use patterns". Haila's findings (2002) support this statement by indicating that human-sourced impacts such as urban development disrupt habitat patterns and thus have negative effects on biodiversity. Therefore, in the methodology of this research, landscape fragmentation is also taken into account for assessing the ecological sustainability performance of a spatial plan. Because it is known that fragmented ecosystems do not perform like the ones more integrated ones and connected to each other. Thus their unity is an important component for reaching ecological sustainability. Therefore it is assumed that ecological sustainability decreases when a land-use type providing ecological benefit gets more fragmented and multipartite. In contrast, for a land-use type that has a negative impact on ecological sustainability, if fragmentation increases, the level of negative impact decreases as well.

In this regard "patch density (PD)" approach is adopted in the analysis to use fragmentation level as a coefficient at EcS level. Patch density approach is selected due to its simple and direct measure of habitat subdivision and its suitability for defining ecosystem fragmentation (McGarigal et.al, 2005). More detailed information about "patch density" is shown in Table 3.4 that is directly gathered from the same study. In calculation, patch density is inversely proportional to the performance of a landscape for providing ES or causing ecological impact (EI) since PD is proportional to the number of patches.

Table 3.3 : Patch density approach.

$PD = \frac{n_i}{A} (10.000) (100)$	n_i = number of patches in the landscape of patch type (class) i. A = total landscape area (m^2).
Description	PD equals the number of patches of the corresponding patch type divided by total landscape area (m^2), multiplied by 10,000 and 100 (to convert to 100 hectares). Note, total landscape area (A) includes any internal background present.
Units	Number per 100 hectares
Range	PD > 0, constrained by cell size.

Within composite sustainability indices, the weighting is another critical factor, which. reflect the relative importance of different aspects of their contributions to the sustainability level of a system (Gan et.al., 2017). The weight assigned to an indicator in an index reflects its relative importance or contribution to the index. A number of weighting techniques exist that lead to different overall results (OECD, 2008). Main weighting approaches are equal weighting, statistical weighting and expert opinion based weighting (Dobbie and Dail, 2013). In ES context, although criticized to include subjective insights, the expert-based weighting has been proven to perform quite efficient while assigning importance levels of ES indicators (Burkhard et.al, 2009, Jacobs et.al, 2014). Jacobs et.al. (2014) state that when the experts are selected from the relevant audience and covers ES related disciplines; average weight values for each indicator can represent consistent results. Therefore, an expert-based weighting is also adopted within this research and it is used as the main method. As a result, it is argued that the ecological sustainability of a plan is the function of the land-use types' EcS scores, land-use types' area, patch density (PD) level of the land-uses and ecosystem weights (ESw).

$$EcS\ level = \sum_n^i LUT_i\ Score\ x\ LUT_i\ Area\ x\ (1/PD_i)\ x\ ESw \qquad (3.1)$$

In calculation, patch density is divided by "1" since it is inversely proportional to EcS level. As of patch density increases, EcS level decreases.

After calculation of EcS level, EcS performance of a land-use plan is calculated as the difference between land-use plan's sustainability level and land cover's sustainability level (Equation 3.2).

$$EcS\ performance = EcS\ Level_{plan} - EcS\ Level_{cover} \qquad (3.2)$$

As mentioned in detail above, this methodology is unique by means of incorporating the ES concept in the definition of sustainability and creating a link between sustainability and land-use plans. The approach is comprehensive by means of reckoning quantitative details of land-use such as its area and integrity. Lastly, by putting ES weights into the analysis, the method becomes more applicable to different locations and cases by enabling to input specific characteristics of that area.

As the second part of the research, a stand-alone GIS tool has been developed to make the assessments effectively. In order to adapt the model into GIS, first of all, some variables had to be pre-defined. As can be seen in Equation 3.1, the sustainability function relies on two critical parameters directly related to ES. These are scores and weights. Naturally, scores and weights for ES are defined prior to calculation because these cannot be read or gathered by a GIS tool automatically since they are non-spatial. On the other hand, these pre-defined variables are stored in a tabular format that can be reached through the developed tool and hence they can be updated easily. All of the pre-defined variables are based on the Corine Land Cover taxonomy as mentioned in the previous section. In other words, the EcS scorings and weightings are based on Corine Land Cover taxonomy. After these steps; the GIS tool demands input data that includes land-use types in .shp (ESRI shapefile) format which is one of the most common data formats for most of the spatial plans. Then the developed software reads the spatial data and calculates the "area" and "patch density" values and writes these values into the data as new fields in the database. In the next step, the system prompts a matching table in case there is an inconsistency with Corine Land Cover and input land-use plan taxonomy. If there are inconsistencies, it is required to couple the land-use type with the best matching land cover type. After the matching process, EcS level for a plan is calculated. Then the same procedure is applied for current land cover in the plan area (within the same locational extents) and the difference is calculated as in Equation 3.2. Then the EcS levels and performances are mapped. The GIS algorithm is summarized in Figure 3.1.
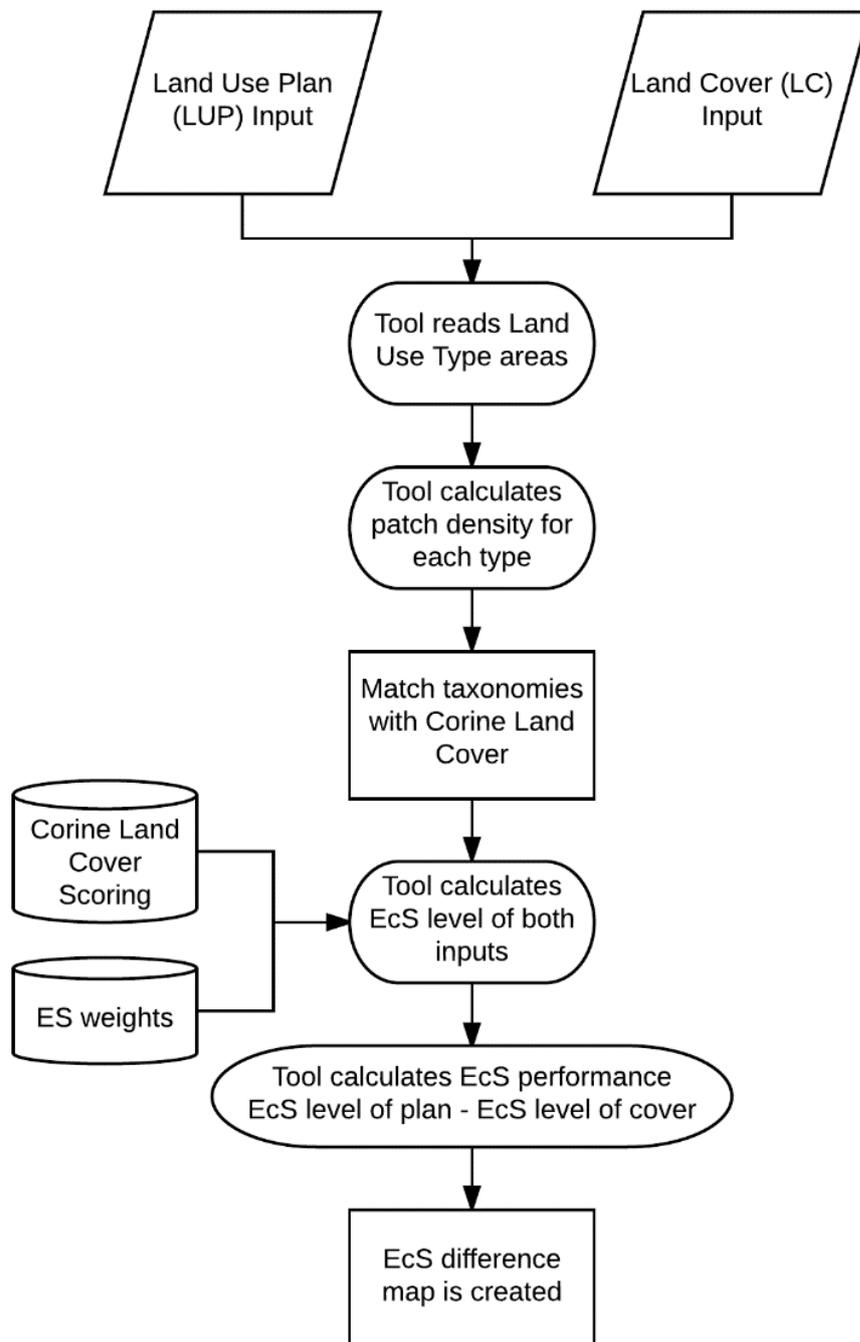
Figure 3.1 : Methodology diagram.

4. IMPLEMENTATION

In this study, to assess EcS performance of the master plan these method steps are applied into the Environmental Master Plan (EMPI) of Istanbul (2009) and Corine Land Cover (CLC) (2006) that was also used as an input in 2009 EMPI. The implementation was carried within two different GIS infrastructure to prove the developed GIS tool's accuracy and reliability. The first implementation was done within the ArcGIS environment while the second one was done within the GIS tool developed throughout this study.

The reasons for using CLC are its widespread use, acknowledged quality and temporal overlap with EMPI. Also by using the taxonomy that CLC offers, it is aimed to enable other researchers to adopt this methodology more easily. Moreover, in the current study of the Istanbul Metropolitan Municipality's EMPI Revision, ES scoring and weighting are done based on CLC taxonomy. Therefore, it was readily adopted in this study.

Implementation steps can be grouped into three tiers. The first tier is the preparation of background data; the second tier is where GIS calculations in vector data format are carried out, and the third tier is final assessments to produce decision support maps based on Equation 3.1 and Equation 3.2.

The first task has been the selection of proper ES indicators based on current literature and specific characteristics of the Istanbul metropolitan area. Then both datasets are given weights scores as explained. However, since there has been scoring only for land cover data of Istanbul, the master plan's taxonomy has been matched with the CLC taxonomy based on the master plan's report and taxonomy explanations. The matching process provides an understanding of what type of land cover is presumed with the proposed land-use. As a result, a scoring table is used for two different datasets, and two scoring tables for each dataset are gathered (Appendix 1&2).

In Tier 2 all datasets are arranged in a GIS environment in vector data format to enable calculations. In this part, incorporation of area quantities, patch density scores, and ES weights are provided, and data is thoroughly prepared for final calculations.

As the last step in Tier 3, EnS level for both datasets has been calculated based on Equation-3.1 in vector data format, and then they are converted to raster. Afterward, Equation two is applied, by using raster subtraction (minus function in ArcGIS) and as a result, the EcS Performance map of EMPI is produced. The implementation process is summarized in Figure 4.1.
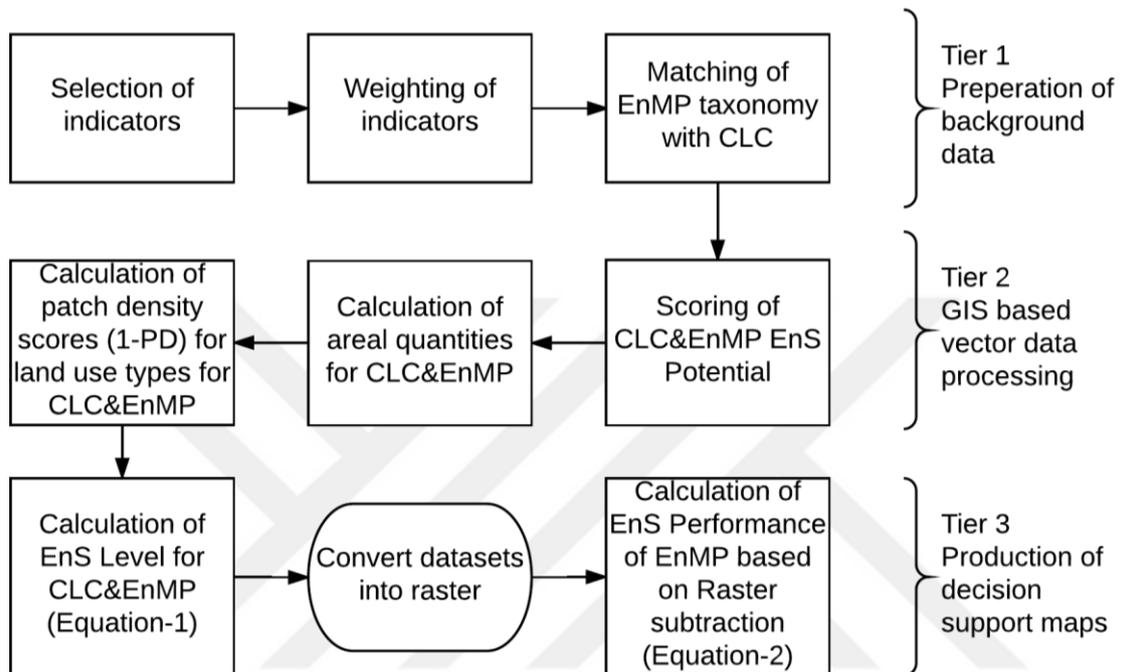
Figure 4.1 : Implementation process diagram.

4.1 Selection of ES indicators

Selected indicators are regulatory ES as described in many ES frames, which are composed of environmental benefits provided by ecosystems. For determining the relevant indicators ES indexes of Millennium Ecosystem Assessment (MA) (2005), The Economics of Ecosystem and Biodiversity (TEEB) (2013) and Common International Classification of Ecosystem Services (CICES) (2013) (Table 3.1) are evaluated. As stated in the methodology section, CICES categorization is used in this research since it is the latest version for ES classification schemes and embraces its predecessors. Moreover, this classification is used by the Istanbul Metropolitan Municipality in the ES mapping process of Istanbul in the EMPI Revision study. Therefore, its compliance with the current practice of planning makes CICES indicators more favorable than other approaches.

4.2 Weighting of indicators

The weighting of indicators is critical because their importance can vary based on location and priorities. Therefore, indicators have to be explicitly handled and given weights to reflect their actual share in the environmental sustainability level. In this study, there were no weightings for the indicator sets, and hence Istanbul Metropolitan Municipality's EMPI Revision Study (2017) is taken into account. In this revision study, ES classification is based on regulating, provisioning and socio-cultural aspects and for each tier expert based weightings are carried out. Based on 82 surveys carried out with 72 different experts from different fields of environment, spatial planning, water, forestry and agriculture; each ES tier is scored and weighted using the AHP method. In accordance with the findings, reports and explanations of the EMPI Revision Study (2017), each indicator set is weighted as given in Table 4.1.

Table 4.1 : Assigned weights for ES.

Ecosystem Services	Weights
Mediation of gaseous/air flows	0,2
Atmospheric composition and climate regulation	0,2
Mediation of liquid flows	0,2
Soil formation and composition	0,1
Pest and disease control	0,1
Natural Hazard Control	0,1
Pollination	0,05
Mediation of waste, toxins and other nuisances by ecosystems	0,05

4.3 Adaptation of Environmental Master Plan's taxonomy into Corine Land Cover taxonomy

In this study, to stay in line with previous ES scorings in literature and provide a global and comprehensive understanding of the analysis, CLC is used as the primary dataset that ES scoring is applied. In other words, the CLC taxonomy provides the basis for calculation. Thereof whole analysis procedure is based on the scoring of the CLC taxonomy. Nevertheless, there are various classification types that are used for land cover; which do not comply with the CLC taxonomy. Moreover, in most cases, land-use plans' classifications are also different from CLC. Therefore, a matching process

is designed within this research where incompatible classification types can be matched with the relevant CLC type. Consequently, both of the input data are converted to datasets that are represented with CLC taxonomy. In implementation procedure, EMPI dataset is matched with CLC in accordance. The matching of land-use types and land cover classes are shown in Table 4.2. More detailed information and background on the matching process can be seen in Appendix-3.

Table 4.2 : Matching of land-use taxonomy of Environmental Master Plan and Corine Land Cover taxonomy.

Spatial use types in the Environmental Master Plan	Matched Corine Land Cover Classes
Area to be integrated ecologically with forests	Transitional woodland-shrub
Military Zones	Transitional woodland-shrub
Dam-lagoons	Water bodies
Bosporus buffer zone	Discontinuous urban fabric
Areas of natural preservation	Natural grasslands
Education, informatics and technology areas	Industrial or commercial units
Expo, fair and festival area	Industrial or commercial units
Areas where development and density will be kept under control	Discontinuous urban fabric
Development areas	Continuous urban fabric
Habitat Park	Natural grasslands
Airports	Airports
Basin rehabilitation area	Natural grasslands, Pastures
High technology area	Industrial or commercial units
Urban and regional service area	Continuous urban fabric
Urban and regional green and sports area	Green urban areas
Shore rehabilitation area	Beaches, dunes, sands
Logistic area	Port areas
Pastures	Pastures
Urban area	Continuous urban fabric
Integrated (Organized) Industrial Areas	Industrial or commercial units
Forest areas	Broad-leaved forest, Coniferous forest, Mixed forest
Beaches and dunes	Beaches, dunes, sands
Health park	Industrial or commercial units
Industrial zones	Industrial or commercial units
Natural parks	Natural grasslands
Agricultural fields	Non-irrigated arable land
Agricultural production development park	Non-irrigated arable land
Shipyard	Port areas
National and international sports area	Sport and leisure facilities
University	Discontinuous urban fabric

4.4 Environmental Master Plan of Istanbul (EMPI)

EMPI of Istanbul was established in 2009 by the Istanbul Metropolitan Municipality (IMM). The plan aims to be the essential instrument of Istanbul's development on a global scale, and it has the assertion of being created with the central aspect of social, environmental and economic sustainability (IMM, 2009). In this regard, IMM's plan focuses on healthy urbanization and functional integrity, establishing solid foundations between ecological structure and sustainability and lastly identification of Istanbul's role at the international level.

EMPI consists of 36 different unique land-use types. The distribution of these types is shown in Figure 4.2. According to the plan, 47% of the areas are the forest, 18% of the areas are agricultural lands, and 10% are urban land-use types. 4% of the LUTs are military zones that are mostly dominated by natural land cover including forests or at least woodlands but also including military facilities. The types that are lower than 4% are grouped under "other land-use types" such as industrial, commercial, new development, water bodies, Bosporus protection zone and more. Most of these areas can be understood as urbanized areas. These results are calculated by using GIS capabilities of ArcGIS software.
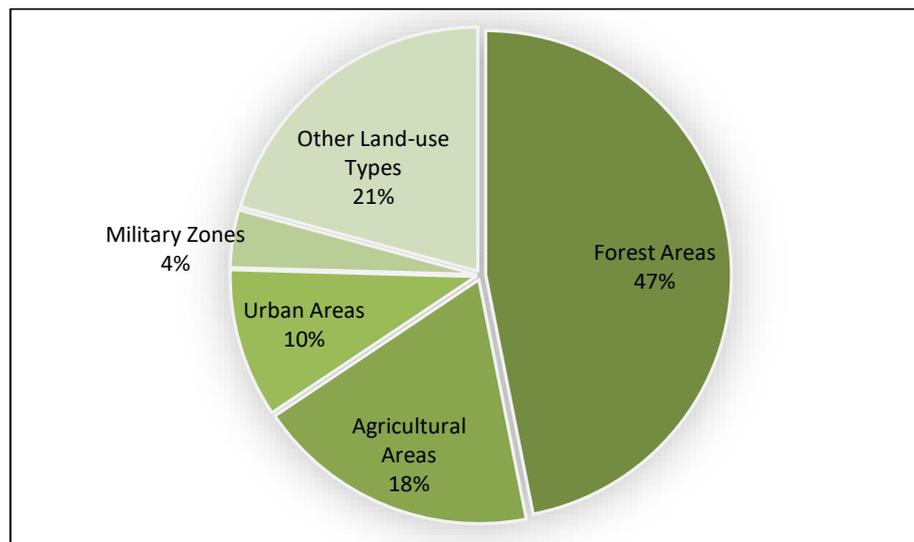

Figure 4.2 : Land-use type distribution in the Environmental Master Plan of Istanbul (IMM, 2009).

The land-use distribution can also be understood from the map view in Figure-5.3, where green areas in the northern part correspond to forests and grey/yellow/brownish areas in the southern part are agricultural zones and urban areas in general.

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Figure 4.3 : Environmental Master Plan of Istanbul (IMM, 2009).

4.5 Istanbul's Corine Land Cover

As stated by Burkhard et al. (2009) Corine Land Cover types can be used as an appropriate spatial and thematic reference for ES assessments as they generate from satellite images and represent the actual situation at the earth's surface. In addition, for the Istanbul case, as considered in this study, their scales exactly fit with EMPI. In "Corine Land Cover Report" (2006) it is indicated that the CLC dataset was generated in 1/100.000 scale since smaller scales lack detail and larger scales include too much detail that prevents the efficiency of its use. Moreover, it is stated that 1/100.000 scale is widespread and used in many studies in different countries and thus can be used as a basis for specific studies at a larger scale within a country, such as preliminary investigations, for city development projects or environmental protection (2000). In Istanbul, CLC consists of 29 unique types for defining land covers. According to the statistics of the 2006 land cover, 48% of the cover is forests, 28% is agriculture-based lands, 13% is urbanized areas, and 3% is water bodies such as lakes or lagoons. Smaller covers are grouped under "other land covers" (Figure 4.4).
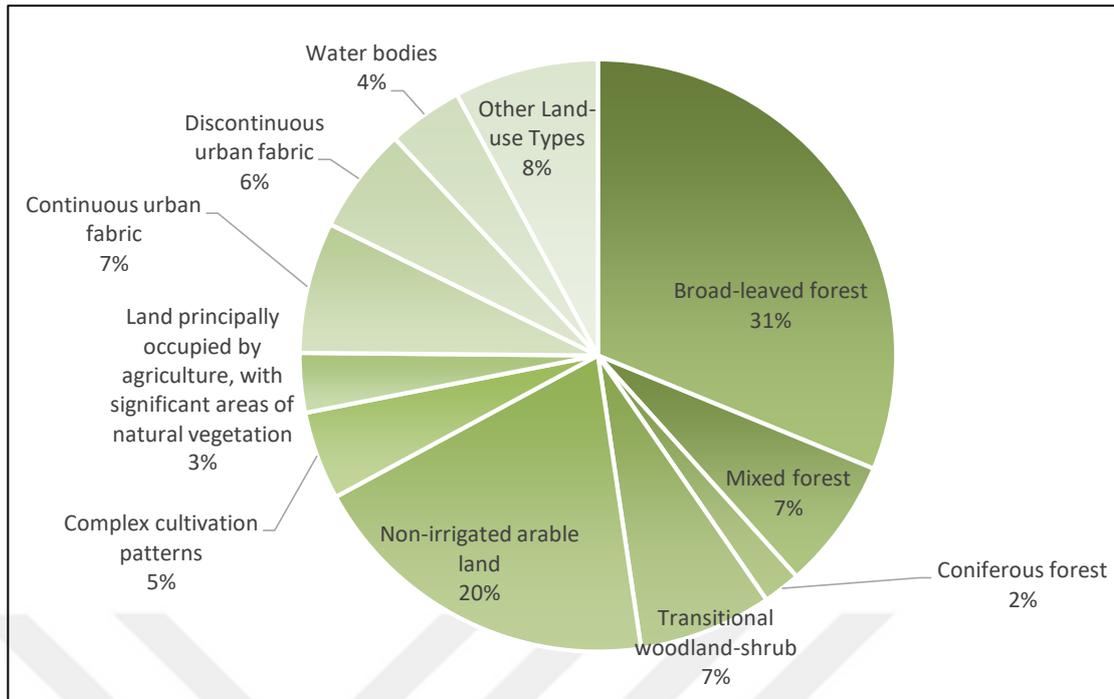
Figure 4.4 : Corine land cover distribution of Istanbul in 2006.

4.6 Calculation of EnS Level for CLC and EMPI

After matching EMPI with CLC taxonomy, EnS scores, area quantities, and patch density values are calculated. Then Equation-3.1 is applied for both datasets in the GIS environment, and results are mapped. First, each land-use type's scoring matrices are constituted based on the surveys carried out by the Istanbul Metropolitan Municipality's EMPI Revision study (2017). In this study, 72 individual surveys were used for the scoring of ES potential of land-use types (IMM, 2017). Nevertheless, since the IMM's study was a derivative of Burkhard's et al. study it did not include score values for impact dimension of land-use plans. Therefore as mentioned in methodology the score matrix was expanded to include negative values for reflecting impact created by the plan. The negative scoring is made based on the knowledge of the authors and literature reviews. The score tables can be seen in Appendix 1&2. Also, it must also be noted that these scorings were produced in Istanbul EMPI Revision Study that is concluded in 2018. However, these values are assumed valid for Istanbul's previous master plan also. Because these scorings rely on a large number of stakeholders and there is no evidence that planning approaches changed drastically in the last nine years.

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After that, as explained in the methodology section, these scores are multiplied with their areal quantities; patch density scores and ES weights. Areal quantities and patch density values are calculated using GIS tools. Then both datasets are converted to raster format to be able to make a subtraction process. The subtraction is done with the aim of understanding the EnS level change in a land-use type. In order to subtract raster datasets, the "minus" function in ArcGIS is used. A simple figure on how the minus function works is shown in Figure 4.5.
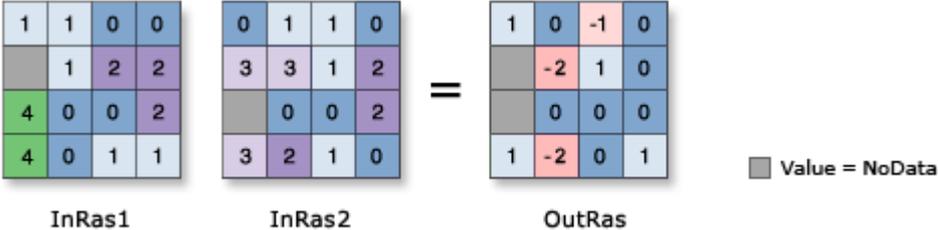
Figure 4.5 : Raster subtraction with the "minus" tool in ArcGIS (, last access on 27.10.2018).

In this study, values in raster grids represent the EcS level of each land-use type. Applying Equation-3.2; subtracting EnS level of CLC from EMPI; gives information on how these environmental sustainability changes and varies based on location, integrity, and quantity of land-use types.

4.7 Evaluation of the Implementation Results

According to the analyses, overall, it is seen that EMPI performs worse than its current land cover. On the other hand, in some parts of the city, it is estimated that EMPI performs better than CLC. In Figures 4.6, 4.6, 4.7 respectively; dark green colors correspond to better EnS scores, and lighter greens correspond to lower EnS levels.

The EnS Performance Map (Figure 4.8) is produced by the subtraction of each map based on *Equation 2*. As a result, it is found out that while CLC performs better than EMPI in especially forest and natural habitats; in urbanized zones, EMPI performs better.
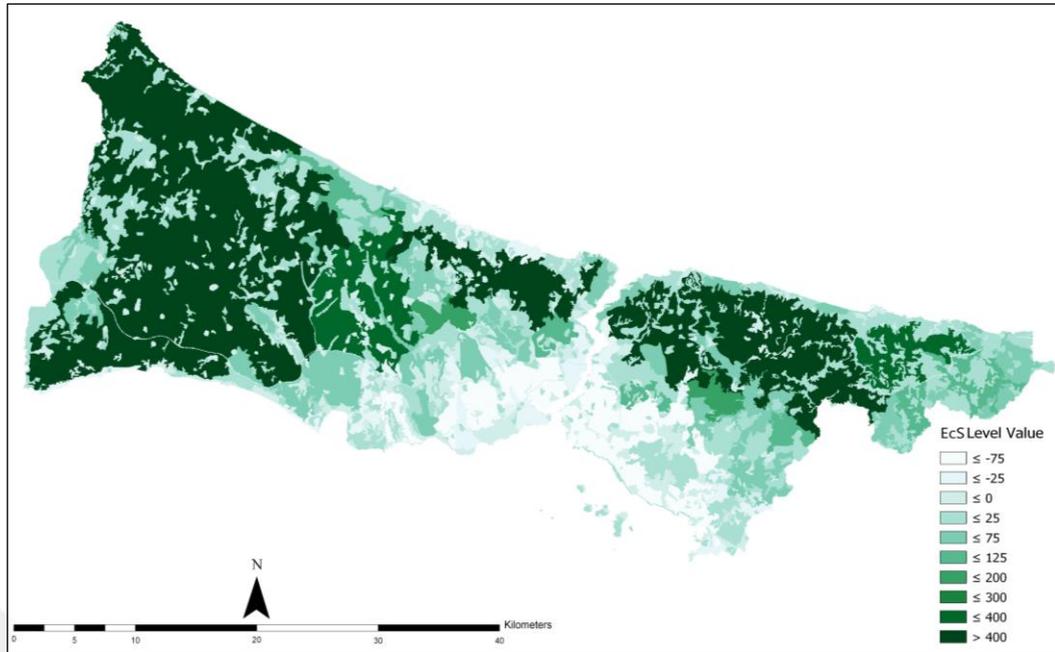
Figure 4.6: EcS Score Distribution Map of CLC
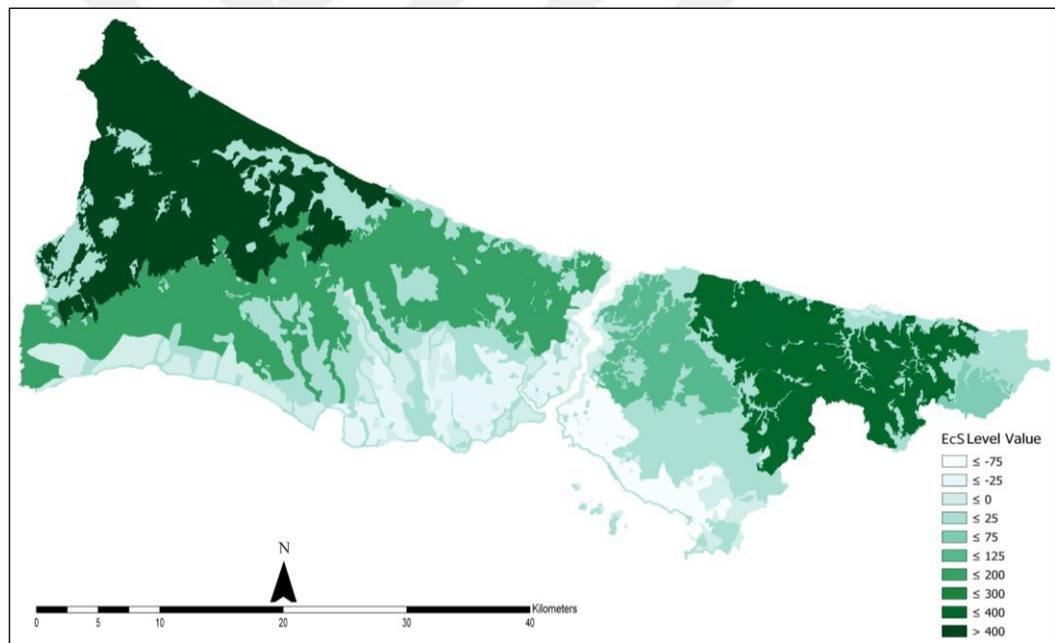
Figure 4.7: EcS Score Distribution Map of EMPI
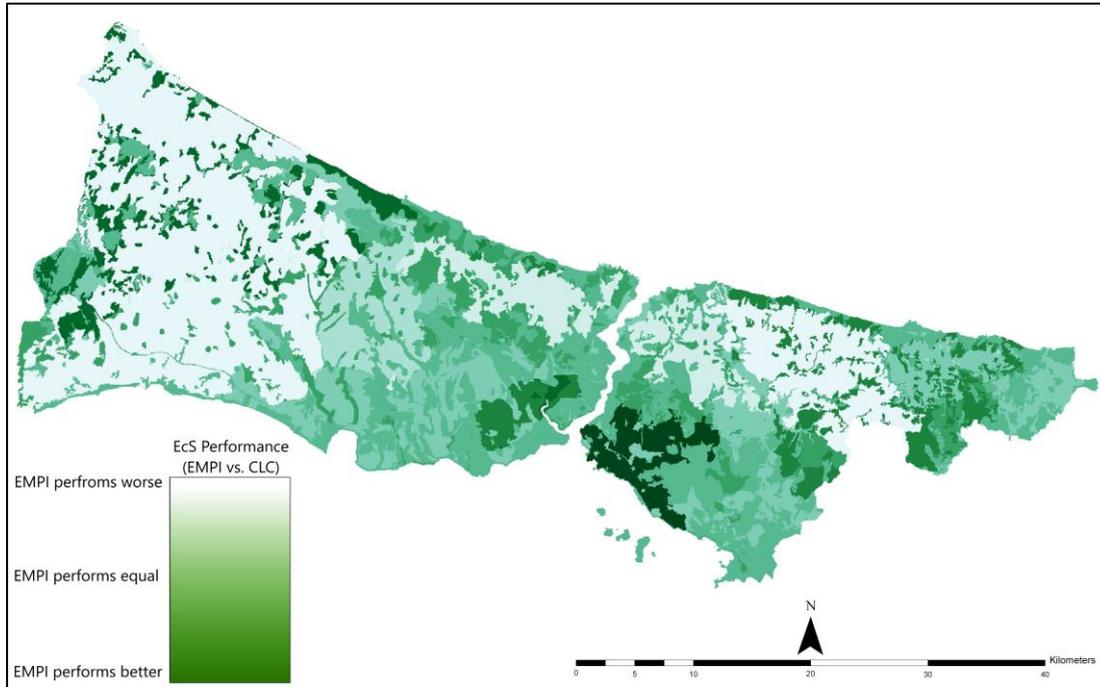
Figure 4.8: EcS Performance Map of EMPI

According to the outputs of the analysis, it is found out that although 2009 EMPI's one of the main aims is achieving environmental sustainability; it is performing worse than its actual land cover significantly and there is a lack of sustainability, especially in forest areas. It can be argued that there is a certain level of decrease in the performance of forest zones. This is not just due to areal loss but also the integrity of the forest land cover is also critical in this sense. On the other hand, in some parts of the city EMPI has more sustainable characteristics particularly in urbanized areas on the Anatolian side of Istanbul.

5. SOFTWARE DEVELOPMENT

The analysis in the implementation proved that the approach gives insight into the performance of the spatial plan by making it available to understand in which aspects it performs well or in which aspects it requires enhancement. Therefore, it enables the planner or decision-maker to enhance the relevant part of the spatial plan. Hence, this approach has significant potential to serve as a decision support tool. In addition, the study is unique and efficient by using ES to define ecological sustainability that serves as a tool for understanding the performance of the spatial plans and spatial patterns. Thereof the developed methodology has the capability to serve as a link between spatial use and ecological sustainability.

It must be noted that expert reviews and related scorings and weightings have an important role in the methodology. Therefore the level of knowledge for the planning area and the phenomenon of ES has a certain impact on the analysis results. Thus, while implementing this method, one must consider a wide range of stakeholders for providing the most accurate scoring as applied in EMPI revision study (2017). Besides, it is more than favorable to have actual measurement data related to land cover and its services/impacts on parameters such as air quality, water levels, and soil structure. In this way, scorings can be enhanced, and more accurate results and predictions can be achieved (Burkhard et.al, 2009, 2014). In the implementation section presented above, there was no available quantitative data in hand to support or refute the expert reviews, and since the scores were in line with literature reviews, they were accepted as they are.

Another vital point to be highlighted is that land-use plans are not the one and only instruments that influence urban or rural development. Actions that do not comply with the plans are also seen in practice, and this can mislead the findings of this analysis. Moreover, although some of the land-use such as urban areas, industrial zones or transportation is seen as a source of environmental impact, technological advancements or legislative obligations can minimize the impact caused by these uses. In this regard, one must consider negative scoring in accordance with the

implementation procedures carried out in the plan area. Otherwise, there is a risk of underestimating the positive impacts of achievements or improvements such as green infrastructure.

Although the implementation process is carried out in the ArcGIS environment, it requires time, software knowledge and data arrangement which are all possible obstacles within a decision support process. Therefore a simple tool that incorporates all steps defined in the methodology and applies all the components as in the implementation section is required to be easily used within spatial planning procedures.

In order to remove this gap, Ecological Sustainability Assesment Tool (EcSAT) is designed with the aim of realizing the developed methodology in the most simple and efficient way for the users. In this section, the overall aspects of the software and its interface is explained in addition to the basic reliability and validation test results.

5.1 General Features of EcSAT

As stated in previous sections, developed methodology is useful for understanding the ecological sustainability level of a spatial plan, making comparisons between different plan scenarios and evaluating the difference between current spatial use and proposed spatial plan. As a result, the methodology provides insight for decision-makers to interpret the developed spatial plans by means of ecological sustainability in each phase of the spatial plan production. In order to provide a simple and robust basis for decision-makers and planners to analyze the possible impacts of spatial plans; the above-mentioned methodology and implementation process is adopted within EcSAT software. The main principle of the software is to enable a comparison between a spatial plan and current land cover data so that decision-makers or spatial planners can interpret the ecological sustainability difference between the actual status of the planning area and the planned status. In addition, EcSAT also allows users to compare two different plans that are developed as alternatives for the same planning area. Thereof planners can also identify the ecological sustainability level of proposed plans and evaluate the differences between scenarios.

In order to implement the methodology in stand-alone software, an interface based on four main categories are designed (Figure 5.1). These categories are divided within

tabs as "comparison view" that is the main interface of the software; "map view" where results are mapped, "scores" where ecological sustainability scores for each pre-defined spatial use type is included and "weights" tab that includes weight factors for each ES type.
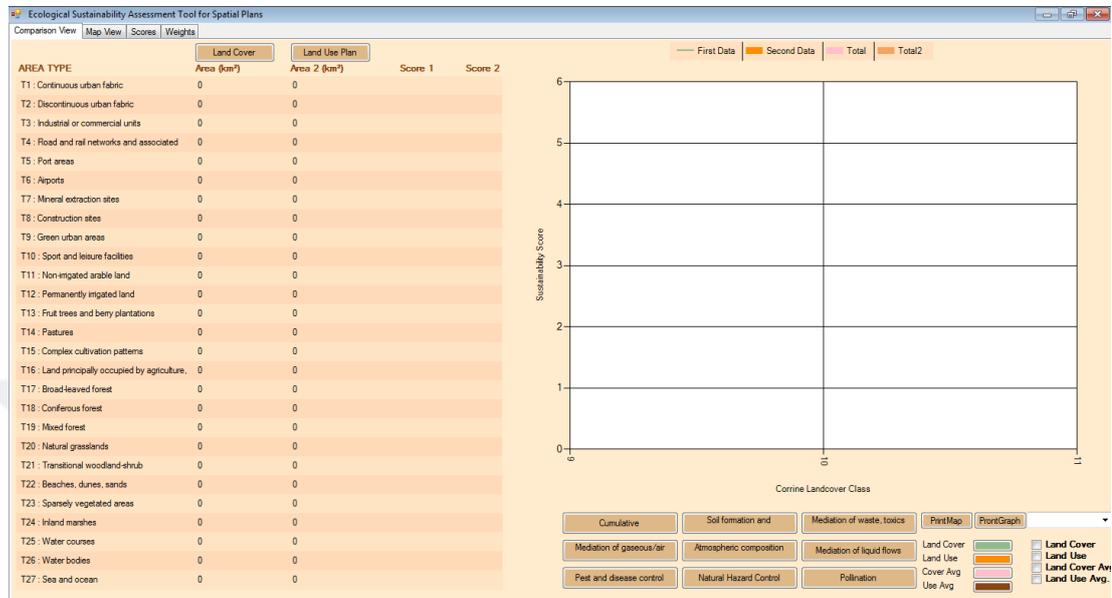
Figure 5.1 : Opening interface of EcSAT.

The interface in "comparison view" tab includes the main functions where the land cover and spatial plans are inputted into the analysis. The left column within this interface includes Corine Land Cover types that are already pre-defined within the tool. The right half of the main interface is for a graphical plot where cumulative or specific ES based variation of graphical drawings can be made automatically.

Map view tab shows a Google basemap as default, fixed to the extent of Istanbul's boundaries (Figure 5.2) which is then used for the thematic representation of the analysis results.
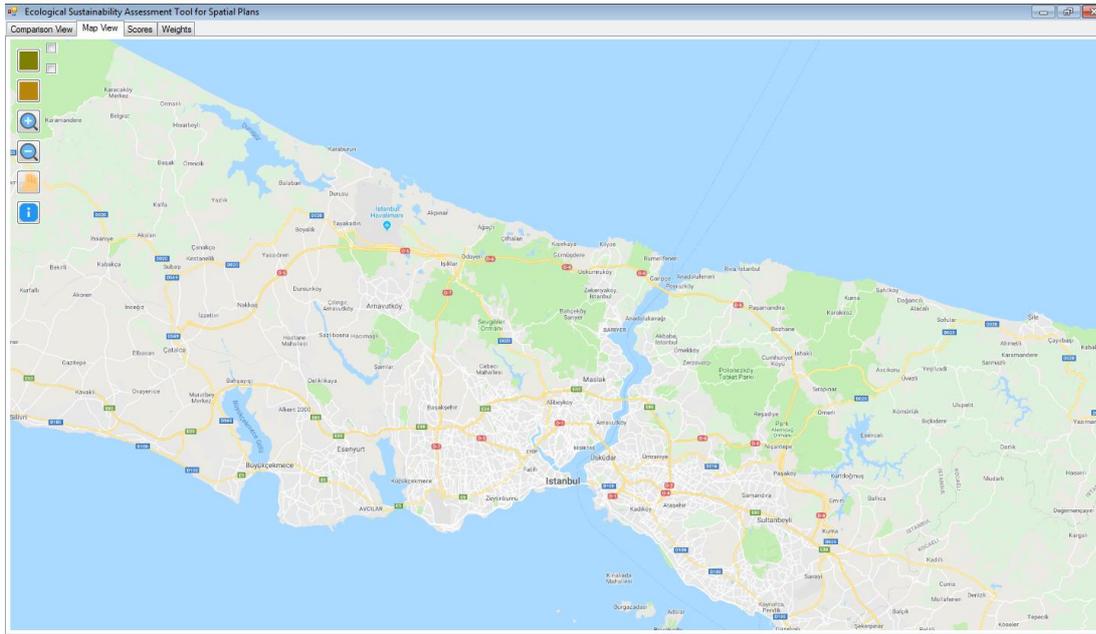
Figure 5.2 : Default map view in EcSAT.

In the scores tab, for each pre-defined CLC type, EcS scores are represented (Figure 5.3) in table format. These values are kept in the Microsoft Access database file (.mdb) in the system and they can be updated based on the case study and user preferences.

ID	ETIKET3	ATMCOMP_CLIMATE_REG	GAS_AIR	LIQ_FLOW	NATURAL_HAZARD	PEST_DISEASE	POLLINATION	SOIL_FORM_COMP	WASTE_TOXIC_OTH
1	Continuous urban fabric	-5	-5	-5	-5	-5	-5	-5	-5
2	Discontinuous urban fabric	-5	-5	-5	-5	-5	-5	-5	-5
3	Industrial or commercial units	-5	-5	-5	-5	-5	-5	-5	-5
4	Road and rail networks and associ...	-5	-5	-5	-5	-5	-5	-5	-5
5	Port areas	-5	-5	-5	-5	-5	-5	-5	-5
6	Airports	-5	-5	-5	-5	-5	-5	-5	-5
7	Mineral extraction sites	-3	-3	-3	-3	-3	-3	-3	-3
9	Construction sites	-5	-5	-5	-5	-5	-5	-5	-5
10	Green urban areas	1	1	1	0	1	1	0	1
11	Sport and leisure facilities	-4	-4	-4	-4	-4	-4	-4	-4
12	Non-irrigated arable land	1	2	2	3	2	2	2	2
13	Permanently irrigated land	3	2	1	2	2	2	1	2
16	Fruit trees and berry plantations	2	2	2	2	3	5	2	1
18	Pastures	1	1	1	1	2	1	1	1
20	Complex cultivation patterns	1	2	2	3	2	2	2	2
21	Land principally occupied by agric...	1	2	2	3	2	2	2	2

Figure 5.3 : EcS scores table in EcSAT.

In the fourth tab, weights for each ES type are kept and they can also be updated based on user preferences (Figure 5.4).

Figure 5.4 : ES weights table in EcSAT.

To carry out the analysis within the software, the main interface is used. First, the input data is entered via "comparison view" tab (Figure 5.1) in .shp (ESRI shapefile) format. The reason for compatibility with .shp format is the widespread use of the format in spatial planning and mapping disciplines. As these data are entered, EcSAT reads the columns of the given data and prompts a dialog box for the user to select the relevant fields for "area" and "spatial use type" (Figure 5.5).
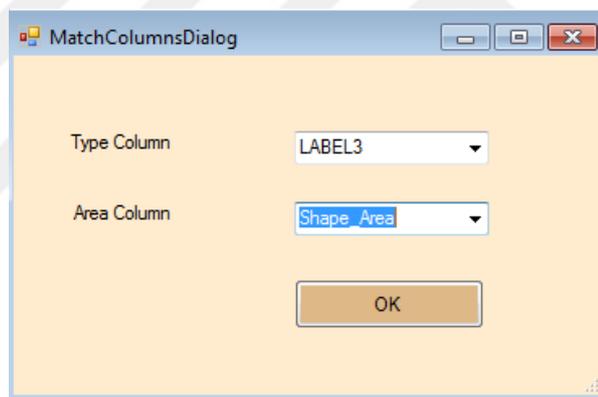
Figure 5.5 : Column matching dialog box.

In order to ensure consistency with Corine Land Cover taxonomy, all of the land cover types are already established within the interface as can be seen in the left part of the opening interface under "Area Type" heading (Figure 5.1). After the type column and area column of the data are selected; another matching box prompts to match the incompatible spatial use types with Corine Land Cover (Figure 5.6).
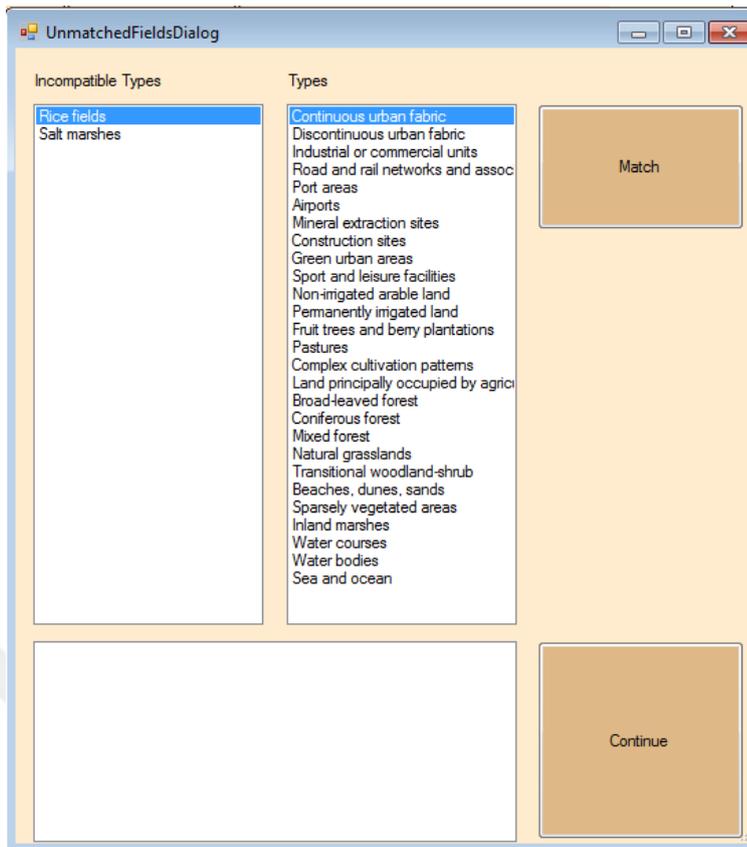
Figure 5.6 : Incompatible column matching dialog box.

As both input data is entered into software, graphics plots are automatically drawn in the graph box (Figure 5.7).
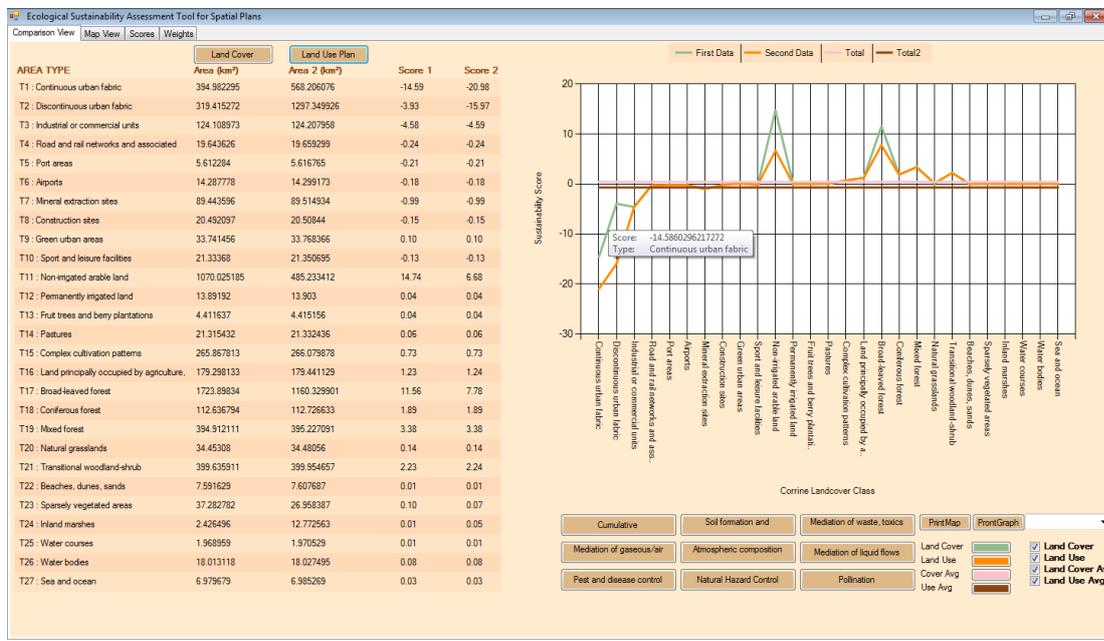
Figure 5.7 : Graphical plots of the analysis results.

These graphs enable the user to evaluate the overall EcS level of a plan and its differentiation with current land cover (or another proposed plan). In addition, it lets the user interpret each ES type's individual impact on the overall EcS level.

Meanwhile, in "map view" EcS level maps for each input data are presented over Google basemap (Figure 5.8 and Figure 5.9).
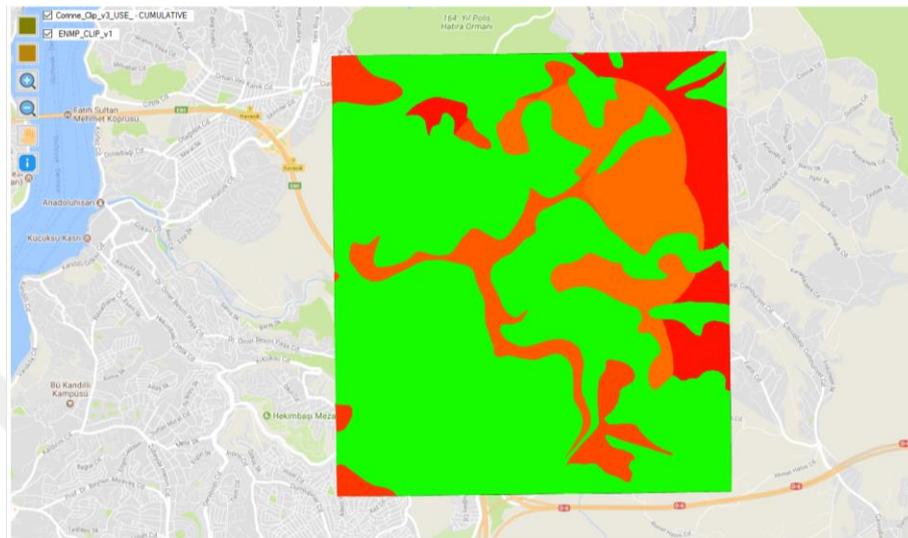
Figure 5.8 : Map view of the analysis for a sample land-use plan input.
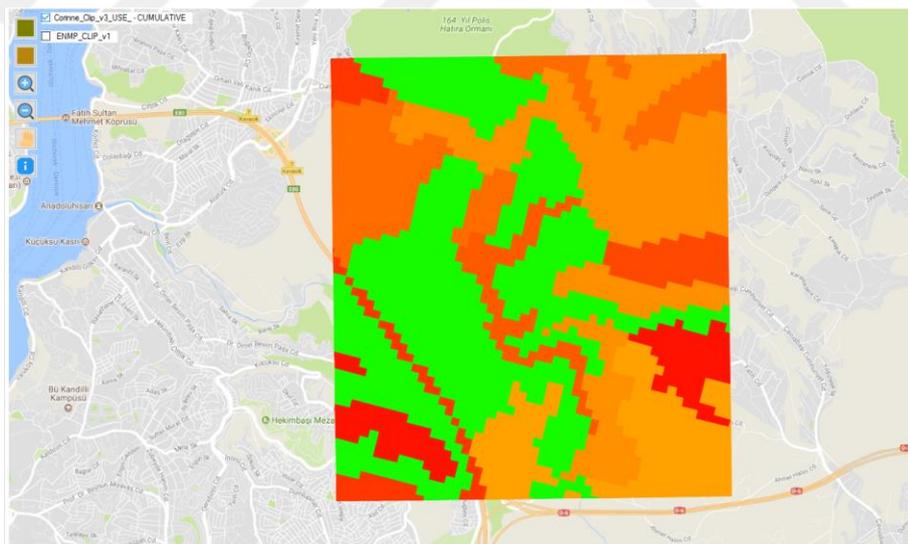
Figure 5.9 : Map view of the analysis for a sample land cover data.

The symbology of the outputs represents the ecological sustainability level of the datasets where ecological sustainability decreases from green to red scale (Figure 5.10).

High sustainability level   Low sustainability level
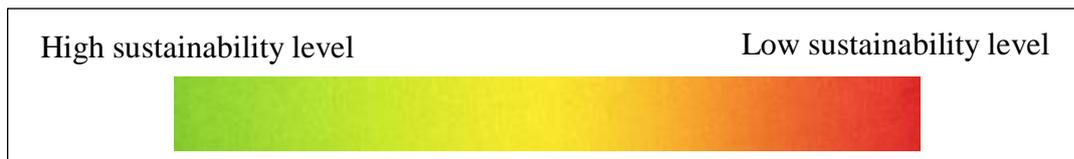
Figure 5.10 : Legend gradient.

As a result of the analysis within EcSAT, two comparable datasets belonging to the same areas can be compared rapidly based on their EcS level. Their level of EcS can be evaluated based on graphic views and map representation. Thereof, the users can easily interpret the pros and cons of a proposed plan compared with its implemented land cover potential.

EcSAT software is developed with ".net framework 4.6" in C# language. To transfer the analysis results in map format, "dotspatial" library is benefited (Url-9).

It must also be noted that in order to apply the developed methodology, there is a certain need of knowledge of spatial use datasets. Someone who aims to use this methodology and software must be familiar with the spatial use types in the planning area and relationship with CLC taxonomy.

5.2 Method Validation

Applied methodology within this research assumes that the ecological sustainability of a given area can be estimated through its ecosystem services potential. In contrast, many other studies as seen in the literature review relies on different types of measurements, observations and data sources to evaluate the sustainability performance (Shane and Graedel,2000; Singh et.al, 2012). In order to validate the methodology applied in this research and EcSAT software; one of the validation tests is to compare the results with another sustainability assessment framework. The main assumption of this test is to evaluate whether EcSAT methodology gives the same results with another acknowledged methodology when comparing entities such as cities, regions or countries. In this regard, Sustainable Development Goals Index (SDGI) (Sachs et.al, 2017) that depends on sustainable development goals developed by United Nations is taken into account due to its acknowledgment at the international level. SDGI compares countries based on their specific properties classified under 17 sub-categories same as in sustainable development goals (Figure 5.11).

Figure 5.11 : Sustainable development goals (UN, 2015).

Since this research focuses on ecological/environmental aspect of the sustainability concept, only relevant SDG indicators have been selected to compare SDG index and EcSAT results. Selected SDGs are SDG-6 (water and sanitation), SDG-11 (sustainable cities and communities), SDG-13 (climate action), SDG-14 (life below water) and SDG-15 (life on land).

In the validation process, each selected country is evaluated in EcSAT and their ecological sustainability level is calculated based on their CLC dataset (2017). It must be noted that EcSAT is developed to compare ecological sustainability levels of a given area's land cover and proposed spatial plan. Thereof, EcSAT calculates two different datasets that belong to the same areal extent whereas SDGI is based on a comparison between different countries. In order to remove possible uncertainties in this regard, a normalization had to be carried out for the selected countries. Otherwise, the country with smaller areal coverage would score lower by means of sustainability level. The normalization is carried out with population data due to its correlation with areal quantity. Secondly, in addition to normalization, countries that are geographically more similar to each other are taken into account to eliminate uncertainties due to geographical differences. Thereof four Scandinavian countries; Finland, Sweden, Denmark, and Norway are considered in the analysis. Based on the validation calculation, it is found out that ranking of the countries in SDGI and EcSAT are the same (Table-5.1) that can be seen as a proof that EcSAT methodology implies with internationally acknowledged approaches and EcSAT can be used as a tool to evaluate ecological sustainability level of cities, regions or even countries.

Table 5.1 : SDGI and EcSAT comparison.

Country	SDG6 score	SDG 11 score	SDG 13 score	SDG 14 score	SDG15 score	SDG overall score	Population	EcSAT Normalized Score	EcSAT Ranking	SDG Ranking
Finland	96,3	99,4	68,7	76,0	67,6	81,6	5.487.000	1,74	1	1
Norway	91,9	98,4	79,9	65,6	67,0	80,5	5.214.000	1,36	2	2
Sweden	95,2	100,0	80,1	59,9	63,1	79,7	9.851.000	1,22	3	3
Denmark	94,1	97,3	83,3	42,4	79,1	79,2	5.707.000	0,11	4	4

5.3 Accuracy of the EcSAT's method implementation process

In order to evaluate the accuracy of EcSAT's method implementation process, a test is carried out to comprehend whether EcSAT gives the same results when the same methodology steps are applied in other software that is Microsoft Excel in this case. In this regard, the land cover and spatial land-use plan data of Istanbul are analyzed within EcSAT (Figure-5.12) and then these datasets are processed to be compatible with Microsoft Excel environment and calculations are carried out in the tabular format. In Figure 5.12, it can be seen that the total ecological sustainability level values for the spatial plan (brown line on top of the graphic) and land cover data (pink line on top of the graphic) are 726,429 and 658,270 respectively.

Tabular analysis results show that EcSAT calculates precisely the same as the tabular analysis (Table 5.2 and Table 5.3). With this comparison, it is proved that developed software EcSAT implements the calculation steps accurately.
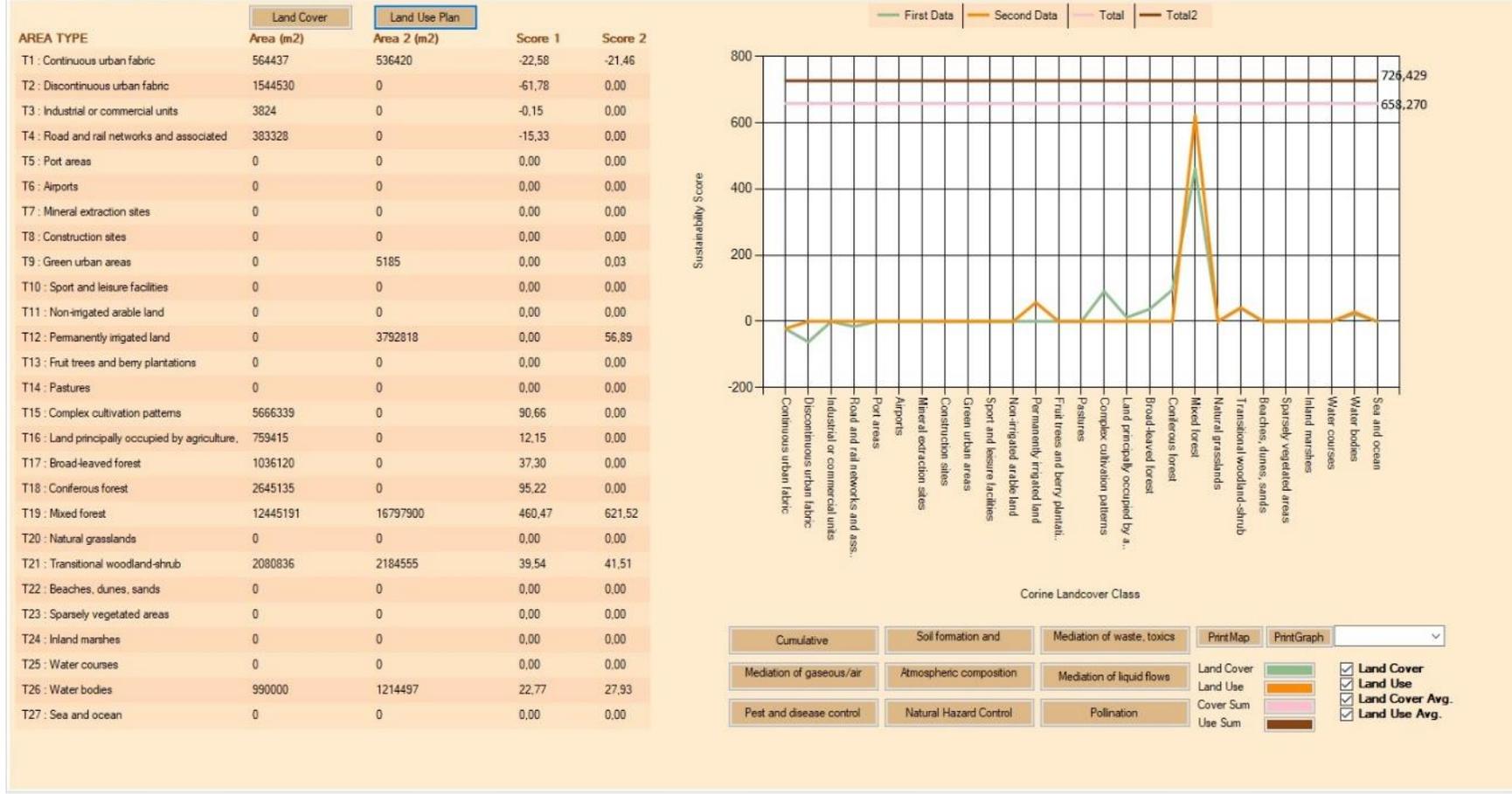
Figure 5.12 : Istanbul's land cover and spatial plan data calculations.

Table 5.2 : Corine land covers analysis in Excel.

Corıne Land Cover type	AREA (100 ha)	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems	Score
	1,036	5	5	4	5	4	4	4	5	37,30
Complex cultivation patterns	5,666	2	1	2	2	2	3	2	2	90,66
Coniferous forest	2,645	5	5	4	5	4	4	4	5	95,22
Continuous urban fabric	0,564	-5	-5	-5	-5	-5	-5	-5	-5	-22,58
Discontinuous urban fabric	1,545	-5	-5	-5	-5	-5	-5	-5	-5	-61,78
Industrial or commercial units	0,004	-5	-5	-5	-5	-5	-5	-5	-5	-0,15
Land principally occupied by agriculture, with significant areas of natural vegetation	0,759	2	1	2	2	2	3	2	2	12,15
Mixed forest	12,445	5	5	4	5	5	4	4	5	460,47
Road and rail networks and associated land	0,383	-5	-5	-5	-5	-5	-5	-5	-5	-15,33
Transitional woodland-shrub	2,081	1	2	3	3	3	2	2	3	39,54
Water bodies	0,990	2	2	5	3	3	3	0	5	22,77
									Overall	658,270

Table 5.3 : Spatial plan analysis in Excel.

Spatial plan functions	Area (100 ha)	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems	Score
Dam-lake	1,214	2	2	5	3	3	3	0	5	27,93
Rehabilitation zone within watershed	2,185	1	2	3	3	3	2	2	3	41,51
Sport and leisure zone	0,005	1	1	1	0	1	0	1	1	0,03
Urban area	0,536	-5	-5	-5	-5	-5	-5	-5	-5	-21,46
Forest area	16,798	5	5	4	5	5	4	4	5	621,52
Agricultural area	3,793	2	3	1	1	2	2	2	2	56,89
									Overall	726,429

5.4 Sanity test

Sanity test is applied for interpreting whether a software algorithm's most basic functions working properly where the goal is to determine if the proposed functionality works roughly as in the expected way (Url-7). To apply a sanity test, two sites that show significant differences by means of ecological assets are evaluated. By that, it is aimed to prove that EcSAT calculates the ecologically rich site is also ecologically more sustainable. The selected areas are Şile and Zeytinburnu districts (Figure 5.12 and 5.13) in Istanbul. According to the land cover data of the districts, Şile includes 60.000 ha of forest area which provides great potential for ecosystem services. Moreover, Şile has a relatively longer coastal zone, includes lakes and watersheds and urbanization is seemingly low. On the other hand, Zeytinburnu is densely urbanized, there is almost no sign of natural habitat and coastal zone is relatively small and more artificial. As a result of the sanity test, it is expected that Şile's ecological sustainability level must be higher than the Zeytinburnu district.
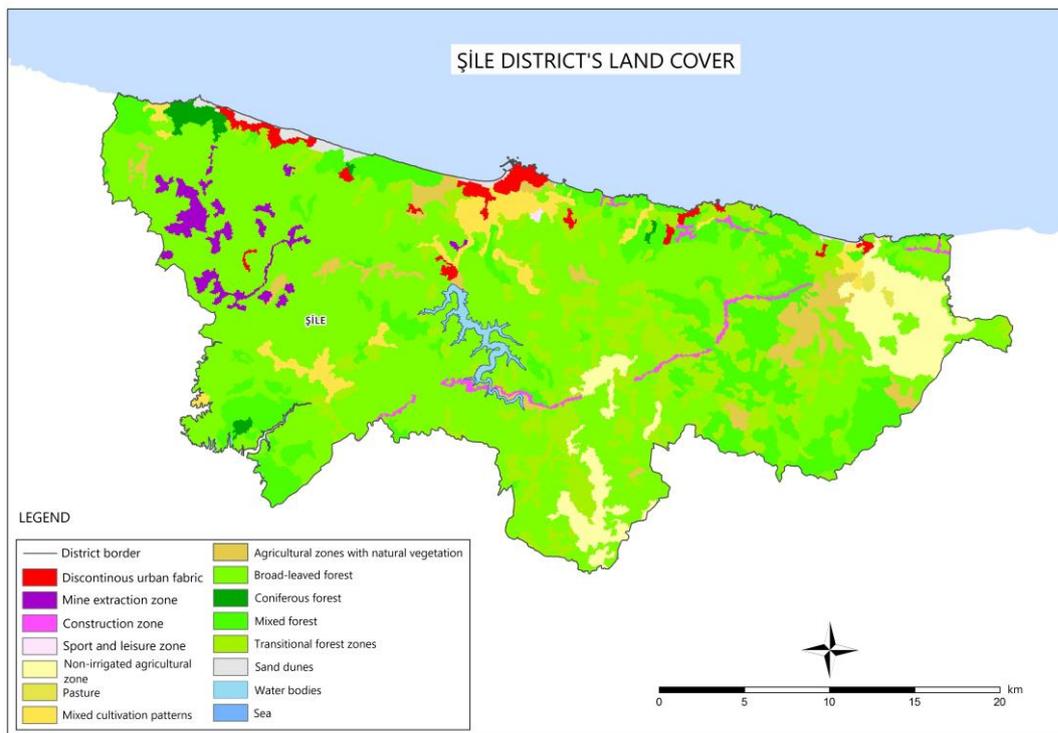
Figure 5.13 : Şile district's land cover data (CLC, 2006).
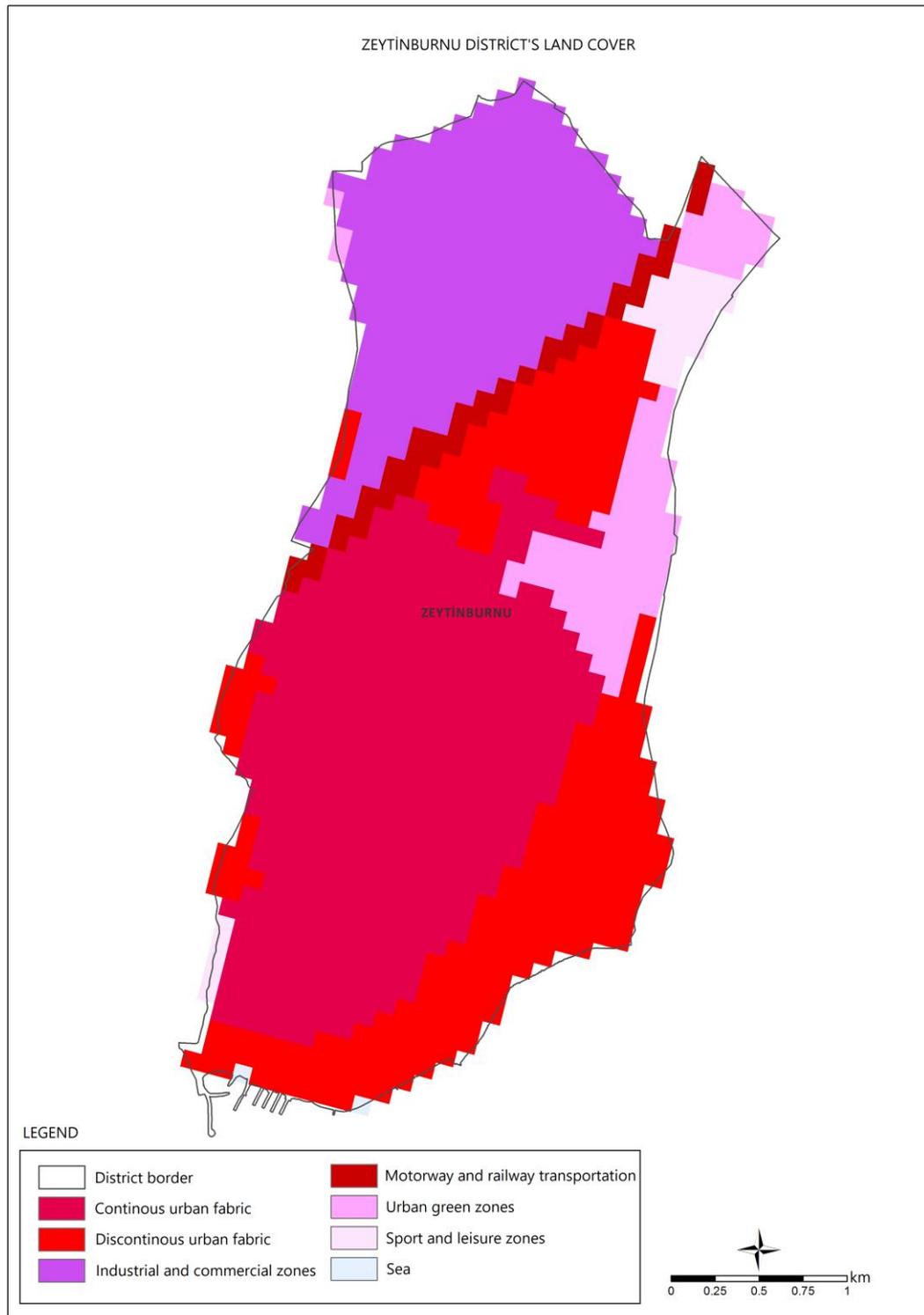
Figure 5.14 : Zeytinburnu district's land cover data (CLC, 2006).

The analysis outputs indicate that Şile's ecological sustainability performance is quite higher than Zeytinburnu. Şile's ecological sustainability score is calculated as 232 (pink line in Figure 5.15) whereas Zeytinburnu's score is -19 (brown line in figure

5.15). In conclusion, it can be stated that EcSAT passes the sanity test and gives reasonable results.
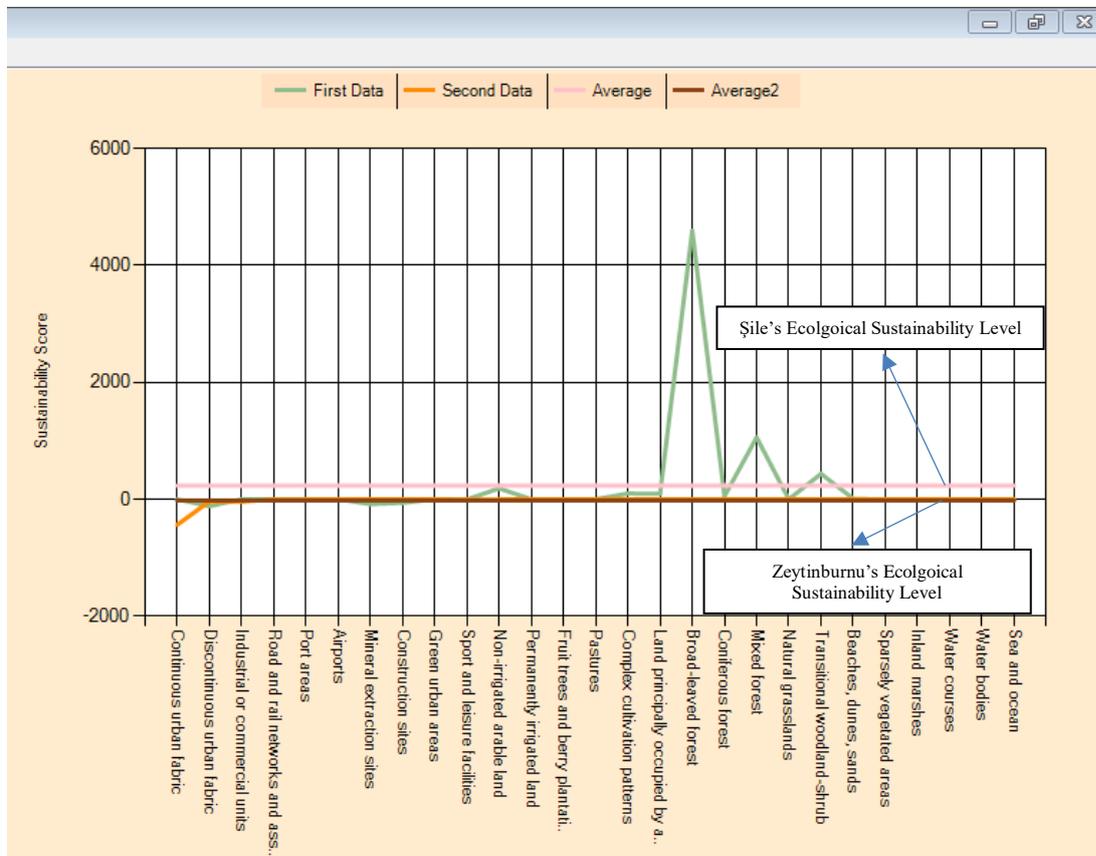
Figure 5.15 : Analysis results of Zeytinburnu and Şile comparison.

6. CONCLUSIONS

Cities are inevitable results of humankind's expansion and evolution on earth and today more than half of the world's population lives in urban areas. The ratio of urban population is likely to increase in the forthcoming years due to cities' attraction potential in accordance with their capacity to offer economic welfare for people. However, urbanization mostly takes place in new lands that usually function as natural landscapes and accommodates a high level of biodiversity. Reenberg and Baudry (1999) state that there are three main results that emerged in the last era due to spatial use change in favor of urbanization:

- Agricultural intensification is increasing sharply and hence, the use of chemicals and pesticides pollute soil and water

- The land is a finite resource and it is non-renewable

- Demand from the urban population on nature and open landscapes is increasing.

Consequently, land degradation is the most tangible result of the urban development process and in order to evaluate and ensure ecological sustainability herein; finite nature of resources and ecological outcomes of spatial use practices must be acknowledged precisely. In this regard, designing and implementing urban development in the most sustainable way is one of the most critical issues in order to maintain the quality and quantity of environmental capital. Thus, spatial planning must be adopted in a way that incorporates ecological concerns, forecasts the possible impacts on ecosystems and takes precautions to assure ecological sustainability.

Nevertheless, although urbanization proceeded rapidly in the last decades, spatial planning discipline has not matched with the pace of urbanization well enough to preserve ecological capital and provide viable cities. Literature suggests that despite the increased number of researches and findings on the importance of ecological value; urbanization has developed against the favor of our living environment and resulted in the loss of natural habitats and landscapes. The fundamental reason behind this reality is that in most cases, the spatial planning process considers ecological concerns within

simplistic approaches and scrutinize environmental aspects based on land cover statistics. Thereof ecological assets are mostly respected as areal quantities instead of living organisms, which leads to neglection of exact biophysical characteristics of ecosystems. In line with this process, spatial plans are created with insufficient knowledge or emphasis on ecological sustainability within the implementation area.

In order to remove the gap between urban development and sustainability context, various studies and methods have been designed to evolve cities' development patterns into a more ecologically sensitive way. Hereof, the most common approach has been to establish indices to evaluate the sustainability level of cities, regions or countries. As mentioned in the literature review, sustainability indices are quite efficient to compare and enable ranking different regions and cities to interpret their sustainability level. Nonetheless, there are reasonable criticisms on these indices, which state the inadequacy of the index assessments to represent the real situation on the ground and to incorporate finite characteristics of ecosystems in analyses. Most times, comparisons rely on relativistic approaches and the sustainability level of the compared entities is appraised in accordance with each other. In other words, relativistic indices compare cities with each other and indicate one of the more sustainable than others while all may be actually unsustainable. Another drawback of such indices is that they concern with the current extent and context of the cities/regions/countries and they do not provide insight into the future projections. Accordingly, there is a certain need to understand the link between absolute characteristics of ecosystems and spatial uses for enlightening decision-makers and planners to reckon the possible ecological impacts of changes in spatial uses for a more sustainable future in cities. By that, the spatial planning process can be enhanced to include all ecological aspects of the planning area and planners can revise the spatial use decisions in favor of sustainability.

Within this context, the ES approach can have an efficient role in relating ecosystem potential with spatial use. ES concept was mainly developed to evaluate and to understand how ecosystem functions provide benefits to a human being. Although criticized to emerge from an anthropogenic point of view, the ES concept is also accepted as a tool to interpret how ecosystems interact and provide multilateral benefits. Therefore incorporating ES into the decision making/planning process is of great importance in order to reckon among the ecological characteristics at the earliest

stage (Genelleti, 2013). Evaluating the capacity of an ecosystem to provide benefits/functions is not so practical though, which requires detailed measurements and observations spreading through a certain period. For example, understanding how a coniferous forest regulates air and increases ai quality can be estimated via observations on air quality parameters such as particulate matter. Moreover, such measurements should be carried out for a certain time frame to produce statistically meaningful results. Regarding the complexity and diversity of ES types and their parameters to analyze, the ES mapping approach has been developed and used in many studies effectively which depend mainly on expert judgments on the level of benefit that an ecosystem can produce. In the ES mapping approach, for a given area, experts give scores for each spatial use type, which represents the ES potential of those spatial use types. Thereof, one can estimate how spatial use provides or does not provide ecological benefit and as a result, it becomes possible to relate spatial decisions with their ecological outputs. In the city scale, by using ES mapping it becomes possible to evaluate the overall performance of a city's ES potential based on its spatial use characteristics. In this regard, the understanding ecological capacity of a city is one of the main steps to have insight into its ecological sustainability. Since ES concept includes different aspects such as regulating, provisioning and socio-cultural; the relevant tier to represent ecological sustainability is presumed to be "regulating" services that include parameters to define how ecosystems regulate our nature. On the other hand, a definition of sustainability suggests (benefits must not be exceeded by effects), understanding a city's sustainability also requires comprehension of negative influences of spatial decisions on ecological processes.

Based on these findings given here; developed methodology within this research is designed to integrate negative aspects of spatial uses into the ES mapping approach and it is assumed that the difference between provided ES and caused impacts due to spatial uses; is equal to the ecological sustainability of a given area. Nevertheless putting up a comprehensive framework to define ecological sustainability in relation to spatial development; requires elaborating on the real quantity of the spatial uses, fragmentation characteristics of the landscape and the weights of the input ecosystem services.

Since spatial planning is a multi-disciplinary, multi-stakeholder and complicated process that depends on a series of technical, social and administrative practices, it is

not feasible or efficient to evaluate quantitatively the performance of each procedure. On the other hand, all of the steps within the planning process end up with a spatial plan that depicts and represents the whole planning procedures in an analytical way. A plan gives information on how the land will be used, how the spatial functions will be arranged and how much area is required. Therefore, in this study spatial plans are taken into account within the methodology as the main input since they can be interpreted quantitatively. Moreover, spatial plans are tools that are mostly created in a GIS environment, which makes them easily adaptable within any related tool, as developed in this research.

Relying on the main axis explained above, the established methodology represents a novelty in several aspects. First of all the analysis is based on the valuation of ecosystem service/ecosystem impact potential of spatial use types based on expert judgment. Therefore one of the main criticisms on sustainability assessments that arise in the literature; which indicates that relativistic approaches lack at highlighting the actual situation and instead lead to misguiding comparisons; are eliminated by involving the absolute value of the ecosystem service (ES)/ecosystem impact (EI) capacity of spatial uses. This method is mostly defined within the ES mapping approach that is proved to perform effectively in representing ecosystem properties on land and by that, the relation between a spatial use type and its ecological characteristics is established and represented in a visual way.

Sustainability definition suggests that in order to reach sustainability difference between benefits and harms must be in surplus. Thus, in the city context, ecosystem services provided within city boundaries must be exceeding ecological impacts caused by the city. Therefore, in sustainability analysis, one must consider the negative side of the occurring by spatial use. In this regard, another important aspect of the methodology is the incorporation of negative aspects of spatial uses within the sustainability analysis. With the developed methodology, it is available to provide a comprehensive evaluation of the advantages and disadvantages of spatial decisions on the ecological sustainability performance of spatial plans. Based on the commonly used ES mapping approach (matrix model) developed by Burkhard et.al. (2009); an addition is made to the concept and ecological impacts of spatial uses are added along with ES. As a result, the main axis of the method is constructed as the "ecological sustainability index".

Established methodology within this research is also comprehensive and novel by means of its complementary aspects. In order to understand the exact environmental conditions arise due to spatial use; quantity and distribution of spatial use types must be considered in addition to ES/EI values of the use functions. Moreover, based on the location of implementation, priorities and perspectives can change which can emerge a need to create variations in the valuation ES/EI. Thereof a weighting factor is also put in the analysis as can be seen in detail in the methodology section. With the integration of all these four components, a holistic calculation method is developed that can serve as a powerful tool for decision-makers to enhance their practices in urban planning in favor of ecological sustainability.

Another novelty of this research comes with the adoption of the methodology in a specific GIS-based tool that can be used with .shp files. The GIS tool enables the users to evaluate the possible outcomes that can occur due to spatial use change. In principle, the comparison is done between a proposed plan and implemented the land's current cover/use. Thereof, decision-makers can easily interpret how the proposed spatial plan will change the ecological state in that specific area. Moreover, the tool enables the users to review and revise the ES scorings and weights of the ES indicators, which lets them specialize in the input in accordance with their needs. Additionally, with graphical and map views the tool makes it possible to perceive what level each ES indicator is changed due to spatial change and where the change is happening.

In conclusion, with this study, a novel methodology and a software module are developed focusing on the assessment of ecological sustainability performance of spatial plans. The approach is a novel by means of handling ecological sustainability as a function of ecosystem services that enable us to comprehend the concept as an absolute entity instead of a relativistic one as given in several sustainability indexes. The developed methodology also provides a holistic but straightforward approach by including capacity, quantity, and weights of the ES indicators and integrity/fragmentation level of spatial use functions. Thus, it is foreseen that developed methodology will provide benefit to strategic environmental assessment processes by incorporating the ES concept into sustainability analyses.

As a result of the research and findings, research questions addressed in the introduction are explained as below:

RQ1: Within spatial development context; how is ecological sustainability defined and measured within acknowledged frameworks and what are the main components of ecological sustainability?

It is observed that ecological sustainability is mostly evaluated based on the outputs such as CO concentration in the air, NO concentration in soil or oxygen level in water resources and many other as indicated before. Nevertheless there is a certain lack of understanding the causes (related with spatial use) that result as those outputs. Thereof this study covers this gap by developing a novel model that defines the missing link between ecological characteristics and spatial use.

RQ2: What is the current situation in considering the ecological concerns in the spatial planning process?

In current spatial planning practice, ecological properties of the planning area are mainly regarded as static assets that cover a space on land. Instead they should be taken into consideration as living and interactive mechanisms that respond to each stimulus occurred by human activities. In this regard, this research covers this gap by adapting ES concept into a tool to estimate ecological sustainability performance of spatial use.

RQ3: How can ecosystems be utilized in order to understand the ecological sustainability level of land-use plans?

As proved in methodology and implementation sections, ecosystems can be utilized in ecological sustainability assessments by using ES mapping method where spatial use and ES capacity of the each spatial use type are scored. In order to do that, ES mapping approach must be revised into a form where spatial use types are considered as sources of EI as well as ES. By that, difference between overall impact and provided services gives an idea about the spatial plan, whether it performs well or not by means of ecological sustainability.

Eventually, with the outcomes of this research, it is hoped that a significant and important contribution to the spatial decision-making process has been completed in the path of reaching sustainable cities. In addition, it is also envisaged that the novelty of this research has the potential to shed light on the sustainability concept and ES research, by linking these two phenomenons in the spatial planning context.

7. DISCUSSION & FUTURE WORK

It must be noted that the methodology within this research is developed to enable analysis with the most basic datasets available such as CLC. Nevertheless, it must be kept in mind that converting a spatial plan's taxonomy (EMPI-2009 in this case) to CLC taxonomy may bring uncertainties since there can be incompatibilities between two taxonomies. Thereof specific indigenous knowledge on the planning area is critical to avoid discrepancies.

The second critic on the method can be regarded as the subjective scoring of the ecological sustainability potential of the spatial use types. As in CLC selection motive, the main reason behind the expert-based evaluation is to remove the need for specific observation data that is costly and timely in most cases. Thereof scoring is used as a catalyzing mechanism that acts as a proxy for observations. Naturally, the most reliable option is to have such observation to avoid inconsistencies but in a methodology that is developed to be used in city or regional level resolution, expert-based knowledge is efficient enough by means of providing stable results.

Another important point to be highlighted is that, although a spatial plan's main axis is given with plan's spatial context (that is provided in GIS format), there are also plan notes that govern the spatial development where these notes can enhance or worsen the characteristics of the spatial use types regarding their ecological sustainability level.

This research must be seen as a contribution to better understand the interlinkage between humankind's use of earth and its effects on ecological processes. Urbanization is the inevitable result of the industrialization era and it is clear that urbanization will continue to grow in the near future. Even though urbanization brings undeniable benefits for a human being, the most significant outcome of the urbanization has been the loss of biodiversity and natural habitats on earth. In light of the sustainable development goals released by the UN in 2015, the sustainability concept is now the main course of action in the development agenda and cities are the most critical domains to act in accordance with these goals. In this regard, although cities are

powerhouses of economic development, expansion of urban areas must transform in a way where ecological concerns take place in the core of the urbanization process.

In this context outputs of this study must be expanded to incorporate all aspects of sustainability (social and economic) where ES concept is presumed to play an essential role by the integration of provisioning and cultural ES into a methodology. By that, a more comprehensive framework will be established in order to provide guidance for sustainable spatial planning.

In line with the enhancement of the methodology, a developed GIS tool must also be revised to match the holistic approach applied. Thus, in order to increase the use and efficiency of the tool, it is planned to develop a module compatible with ArcGIS, which will eventually make it possible for the tool to reach wider audiences.

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APPENDICES

APPENDIX A: ES Capacity Scoring for 2006 CLC in Istanbul.

APPENDIX B: ES Capacity Scoring for 2009 EMPI.

APPENDIX C: Background information on how CLC taxonomy matched with EMPI.

APPENDIX A:ES Capacity Scoring for 2006 CLC in Istanbul.

Corine Land Cover Classification (Based on LABEL3 in GIS data)	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems
Continuous urban fabric	-5	-5	-5	-5	-5	-5	-5	-5
Discontinuous urban fabric	-5	-5	-5	-5	-5	-5	-5	-5
Industrial or commercial units	-5	-5	-5	-5	-5	-5	-5	-5
Road and rail networks and associated land	-5	-5	-5	-5	-5	-5	-5	-5
Port areas	-5	-5	-5	-5	-5	-5	-5	-5
Airports	-5	-5	-5	-5	-5	-5	-5	-5
Mineral extraction sites	-3	-3	-3	-3	-3	-3	-3	-3
Construction sites	-5	-5	-5	-5	-5	-5	-5	-5
Green urban areas	1	1	1	0	1	0	1	1
Sport and leisure facilities	-4	-4	-4	-4	-4	-4	-4	-4
Non-irrigated arable land	2	1	2	2	2	3	2	2
Permanently irrigated land	2	3	1	1	2	2	2	2
Fruit trees and berry plantations	2	2	2	2	3	2	5	1
Pastures	1	1	1	1	2	1	1	1
Complex cultivation patterns	2	1	2	2	2	3	2	2
Land principally occupied by agriculture, with significant areas of natural vegetation	2	1	2	2	2	3	2	2
Broad-leaved forest	5	5	4	5	4	4	4	5

Corine Land Cover Classification (Based on LABEL3 in GIS data)	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems
Coniferous forest	5	5	4	5	4	4	4	5
Mixed forest	5	5	4	5	5	4	4	5
Natural grasslands	1	2	3	3	3	2	2	3
Transitional woodland-shrub	1	2	3	3	3	2	2	3
Beaches, dunes, sands	0	0	1	1	1	5	0	1
Sparsely vegetated areas	1	1	1	1	2	1	1	1
Inland marshes	0	3	4	2	3	4	2	4
Water courses	1	1	3	3	3	3	0	5
Water bodies	2	2	5	3	3	3	0	5
Sea and ocean	1	3	1	0	3	0	0	5

APPENDIX B: ES Capacity Scoring for 2009 EMPI

LAND-USE TYPES IN EMPI	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems
Area to be integrated ecologically with forests	1	2	3	3	3	2	2	3
Military zones	1	2	3	3	3	2	2	3
Dam-lagoons	2	2	5	3	3	3	0	5
Bosporus buffer zone	-5	-5	-5	-5	-5	-5	-5	-5
Area where natural character will be preserved	1	2	3	3	3	2	2	3
Education, informatics and technology areas	-5	-5	-5	-5	-5	-5	-5	-5
Expo, fair and festival area	-5	-5	-5	-5	-5	-5	-5	-5
Areas where development and density will be kept under control	1	2	3	3	3	2	2	3
Development areas	-5	-5	-5	-5	-5	-5	-5	-5
Habitat Park	1	2	3	3	3	2	2	3
Airports	-5	-5	-5	-5	-5	-5	-5	-5
Basin rehabilitation area	2	1	2	2	2	3	2	2
High technology area	-5	-5	-5	-5	-5	-5	-5	-5
Urban and regional service area								
Urban and regional green and sports area	1	1	1	0	1	0	1	1
Shore rehabilitation area	0	0	1	1	1	5	0	1
Logistic area	-5	-5	-5	-5	-5	-5	-5	-5
Pastures	1	1	1	1	2	1	1	1

APPENDIX B (continued): ES Capacity Scoring for 2009 EMPI

LAND-USE TYPES IN EMPI	Mediation of gaseous/air flows	Atmospheric composition and climate regulation	Mediation of liquid flows	Soil formation and composition	Pest and disease control	Natural Hazard Control	Pollination	Mediation of waste, toxins and other nuisances by ecosystems
Urban area	-5	-5	-5	-5	-5	-5	-5	-5
Integrated (Organized) Industrial Areas	-5	-5	-5	-5	-5	-5	-5	-5
Forest areas	5	5	4	5	5	4	4	5
Beaches and sand dunes	0	0	1	1	1	5	0	1
Health park	-5	-5	-5	-5	-5	-5	-5	-5
Industrial zones	-5	-5	-5	-5	-5	-5	-5	-5
Natural parks	1	2	3	3	3	2	2	3
Agricultural fields	2	3	1	1	2	2	2	2
Agricultural production development park	2	1	2	2	2	3	2	2
Shipyard	-5	-5	-5	-5	-5	-5	-5	-5
National and international sports area	-4	-4	-4	-4	-4	-4	-4	-4
University	-5	-5	-5	-5	-5	-5	-5	-5

APPENDIX C : Background information on how CLC taxonomy matched with EMPI.

- Area to be integrated ecologically with forests: Places where significant potential exist for forestation but somehow disturbed by anthropogenic effects. Hence these areas accounted for "transitional woodland-shrubs."
- Military zones: These areas are mostly covered with natural green fields with a significant amount of forest but also includes military facilities. Hence, these areas accounted for "transitional woodland-shrubs."
- Dam-lagoons: Facilities where large and permanent water bodies occur. Therefore, they are directly matched with "water bodies."
- Bosporus buffer zone: Although this definition of land-use function does not imply anything about its cover, this area is urbanized with some green spaces in between the urban fabric. Therefore, we matched this function with "discontinuous urban fabric".
- Areas of natural preservation: These areas have a significant characteristic as "natural grasslands." Thus, their natural state must be protected.
- Education, informatics and technology areas: These areas are designed for the accumulation of technological and R&D sectors. They are directly related to "industrial/commercial" units.
- Expo, fair and festival area: These areas are for specific events such as fairs and festivals. They are directly related to "industrial/commercial" units.
- Areas where development and density will be kept under control: These areas are basically in an urbanized form, but they are usually close to a natural preservation zone or have limitations for more development. Hence, it is matched with "discontinuous urban fabric."
- Development areas: These areas are currently not urbanized densely, but shortly, they are available to become urbanized entirely. Hence, we preferred to match with "continuous urban fabric."
- Habitat Park: These areas are dominated by their natural properties. Hence, they are accepted as "natural grasslands."
- Airports: These areas are directly matched with "airports."
- Basin rehabilitation area: These areas are natural zones but affected by anthropogenic interference, and thus, they must be rehabilitated. These are complex areas including several types of CLCs. Therefore we adopted three different types of CLCs for this type: "Natural grasslands, Pastures, Non-irrigated arable land."
- High technology area: These areas are planned to serve as clustering the high technology investments in a specific zone. Therefore they are matched with "industrial and commercial units".
- Urban and regional service area: These areas usually take place in urban areas and provide public services to education, health or religion. In this regard, they are a part of the built-up environment and can be considered as "continuous urban fabric."
- Urban and regional green and sports areas: These areas have recreational functions, and they are matched with "urban green area."
- Shore rehabilitation area: these areas are currently placed near seashores, but they are most harmed by human activities. Rehabilitation of these areas will transform these zones into "beaches, dunes, sands."
- Logistic area: Although logistic area terms may include different aspects of logistics, in Istanbul they are designed as "port areas."

- Pastures: These areas are directly matched with "pastures."
- Urban area: These areas are directly related to "continuous urban areas."
- Integrated (Organized) Industrial Areas: These are areas clustering places for industrial facilities. They are directly related to "industrial and commercial units."
- Forest areas: In CLC 2006 for Istanbul there are three types of forests consisting of coniferous, broad-leaved and mixed type. However, in the plan, there is only one type called "forest," so we had to make a decision on which type suits the best. Although natural forest land cover is broad-leaved in Istanbul, there very widespread coniferous implantations. Hence we preferred to use "mixed type forest" land cover.
- Beaches and dunes: These areas are directly matched with "beaches, dunes, and sands."
- Health park: These areas are designed for serving for the health sector by utilizing a vast amount of land. Hence they are considered as "industrial and commercial units."
- Industrial zones: These are areas clustering places for industrial facilities. They are directly matched with "industrial and commercial units."
- Natural parks: These areas are directly related to "natural grasslands."
- Agricultural fields: These areas are where irrigated agriculture is most dominant in Istanbul. Therefore we preferred "non-irrigated arable land."
- Agricultural production development park: These areas are agricultural lands, but they are considered as a particular R&D area for agricultural investments. Hence we matched this type with "Land principally occupied by agriculture, with areas of natural vegetation" and "sparsely vegetated areas."
- Shipyard: These areas are directly matched with "port areas."
- National and international sports area: These areas are directly matched with "Sport and leisure facilities."
- University: These areas are designed for university settlements, and they mainly include educational facilities. However, usually, they are not built up densely. Therefore it is logical to assume these LUTs as "discontinuous urban fabric."

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